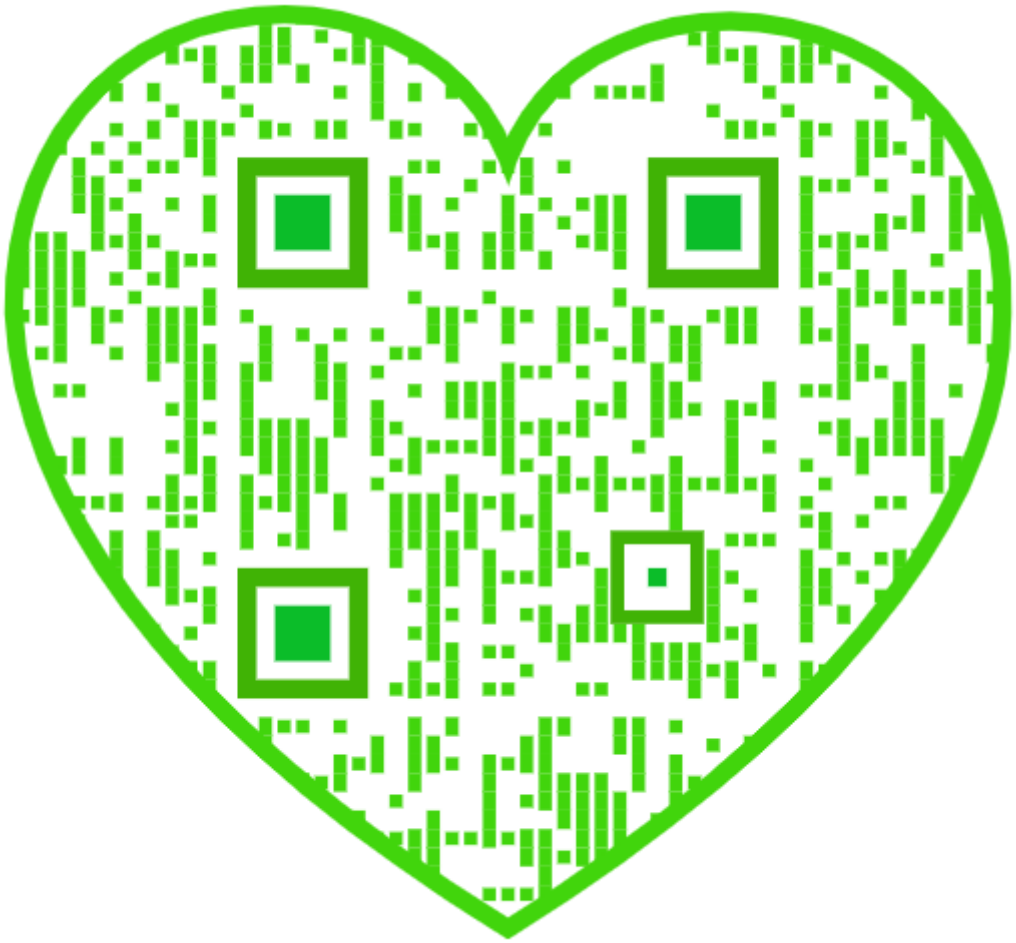

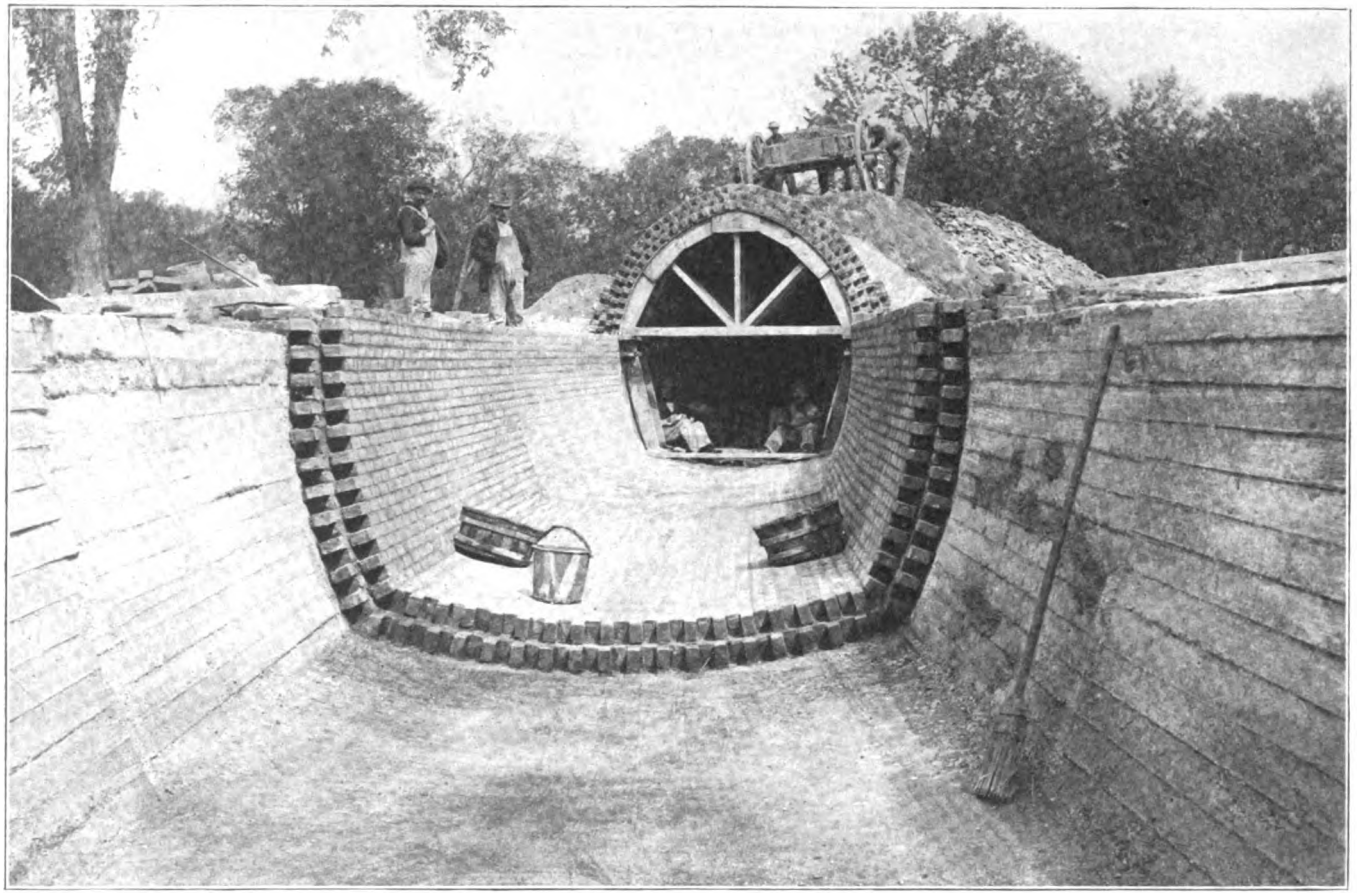

BOTTOM OF TRENCH OF CONCRETE AND BRICK-LINED SEWER

The entire work is covered with an earth embankment after completion. Metropolitan Water and Sewerage System of Boston, Mass.

Sewers and Drains

A Practical Treatise on the

SELECTION, DESIGN, AND CONSTRUCTION OF PUBLIC AND DOMESTIC SEWERAGE AND DRAINAGE SYSTEMS, AND SEWAGE-DISPOSAL PLANTS FOR CITIES, TOWNS, AND OTHER MUNICIPALITIES, INCLUDING ALSO LAND DRAINAGE AND COST CALCULATIONS

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ILLUSTRATED

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Foreword

IN recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

¶ In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

¶ These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the com-

mon understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

¶ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

¶ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

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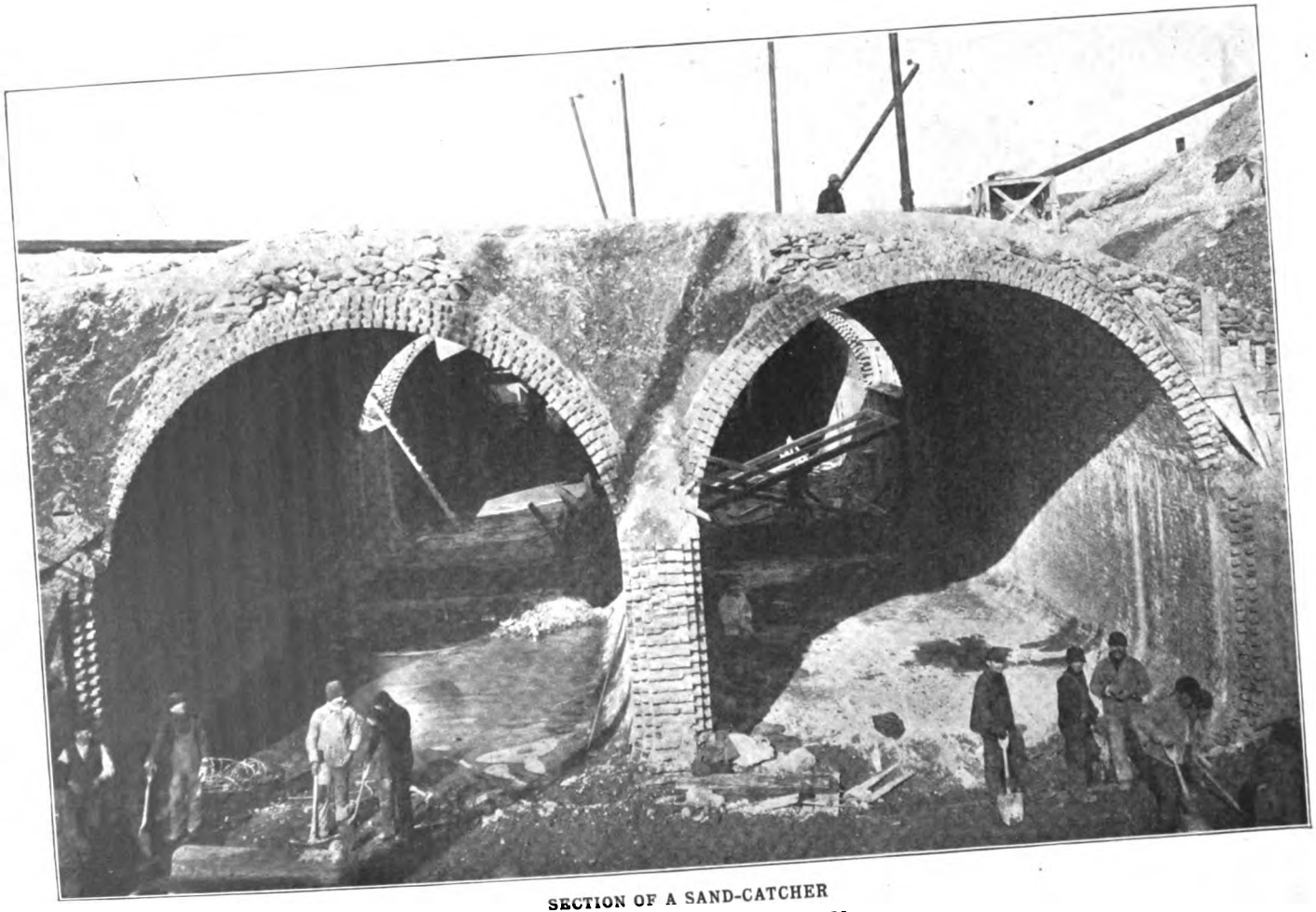

SECTION OF A SAND-CATCHER

Metropolitan Sewerage System, Boston, Mass.

SEWERS AND DRAINS

PART I

1. Introductory Definitions and Discussions. *Sanitary Engineering* is that branch of engineering which has to do with constructions affecting health. It thus might be claimed to include the manufacture and transportation of foods, the architecture of buildings, and many other things which affect the health of communities; but in ordinary use, a more restricted definition of the term is adopted.

In common practice, the term *Sanitary Engineering* is taken to include only *water supply engineering* and *sewerage engineering*, the former branch dealing with securing a satisfactory supply of water, and the latter with the satisfactory removal of surplus and waste liquids. Sewerage is the subject of this instruction paper, water supply being treated by itself.

Sometimes *sanitary engineering* is given a still more restricted meaning, and is taken to include sewerage only.

A *drain* is a canal, pipe, or other channel for the gradual removal of liquids. In sanitary engineering, the two principal kinds of drains are, first, those for the removal of comparatively pure ground waters and surface waters, as in land drainage; and, second, those for the removal of polluted liquids, as in sewerage systems.

A *sewer* is a drain for the removal of foul, waste liquids. Usually sewers are closed, underground conduits. An *open sewer* is an open channel which conveys foul, waste liquids.

Sewerage is a general term referring to the entire system of sewers, together with any accessories, such as pumping plants, purification works, etc. Thus we may speak of the "sewerage" of a city, or of the "system of sewerage," or of the "sewerage system."

Sewage is any foul, waste liquid.

Sanitary sewage is the foul wastes of human or animal origin from residences, stables, stores, public buildings, and other places of human or animal abode. By far the greater part (usually 99.8 per cent or more) of sanitary sewage, commonly, is ordinary water, which

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is added to the wastes themselves in this large volume simply to facilitate removal.

Manufacturing sewage is the foul wastes from factories. In different factories, it is of extremely different nature. It is often exceedingly strong, and very offensive and difficult to dispose of, as compared with sanitary sewage.

Storm sewage is the storm water flowing from city surfaces during and after rainstorms. Though polluted, especially at the beginning of a storm, from the droppings of animals and the other surface filth of cities, it is not so foul, nor so liable to swarm with disease germs, as is sanitary sewage.

The terms *sewage* and *sewerage* are often misused by persons not engineers, to mean the same thing. Thus such persons often speak of the "sewage system" instead of the "sewerage system;" of the "disposal of the sewerage" instead of the "disposal of the sewage," of a city. So common is the misuse that some sanction can be found in the dictionaries; but engineers should be careful to restrict the meaning of the word "sewage" to the liquid which flows in the sewers, while the word "sewerage" should never be so applied.

Sewer air, often miscalled *sewer gas*, is the air in the sewers above the liquid contents. It has no definite chemical composition, but contains varying proportions of pure air and of carbonic acid gas, marsh gas, sulphuretted hydrogen, and the various products of decaying organic matter. Sewer air is constantly changing in composition even in the same sewer. While considered injurious to health when breathed, it has not been proved to be in itself the direct means of communicating infectious diseases.

2. Historical Review. Sewers and drains are of very early origin. Among the ruins of all ancient civilizations, are found the remains of masonry and tile conduits constructed for drainage purposes.

In Fig. 1, for example, (from Fergusson's *History of Architecture*), are shown the remains of a large masonry sewer or drain built by the ancient Assyrians in the eighth or ninth century B. C., for one of their palaces at Nimrud. This is one of the earliest examples found of the use of the arch in masonry.

In Fig. 2 is shown the mouth of the *Cloaca Maxima*, or great sewer, of ancient Rome, built in the seventh century B. C., and still

in use after the lapse of 2,500 years. Without this sewer, a large tract of ancient Rome could not have been inhabited; and in speaking

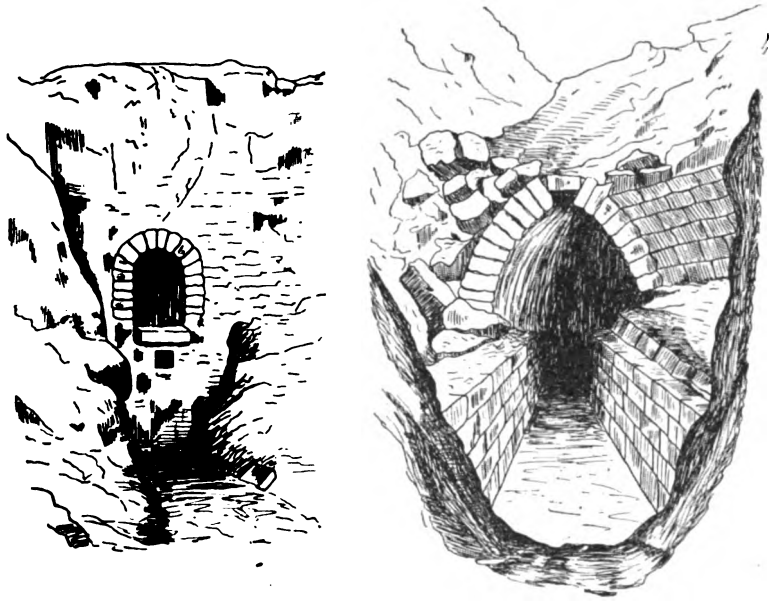


Fig. 1. Ancient Assyrian Sewers at Nimrud.

of it, one authority says: "To this gigantic work, admired even in the time of the magnificent Roman Empire, is undoubtedly owing the

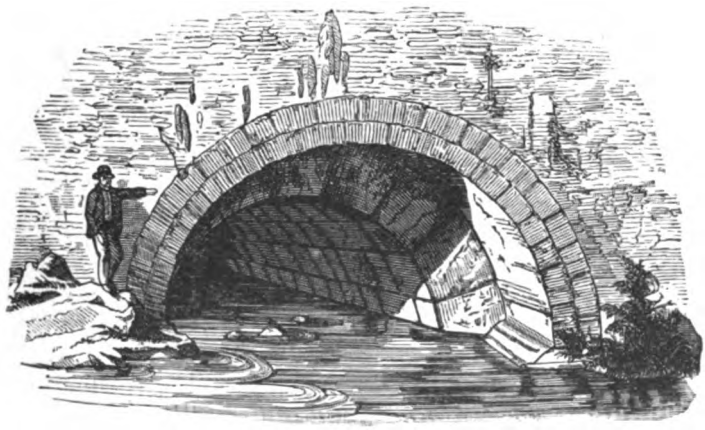


Fig. 2. Mouth of the *Cloaca Maxima*, or Great Sewer, of Ancient Rome.

preservation of the Eternal City, which it has secured from the swamping that has befallen its neighboring plains."

In many other ancient cities and structures, the remains of intelligently planned drainage systems have been discovered; and it is evident that the ancients paid great attention to this matter so vitally affecting health. The art reached its highest ancient development in the time of the Roman Empire. The Romans, in fact, were the greatest engineers of antiquity, and especially excelled in sanitary engineering (both water supply and drainage). They were proficient in land drainage, as well as in sewerage.

With the fall of the Roman Empire, sanitary engineering suffered the same retrogression which befell learning and science; and for a thousand years—throughout the Middle or Dark Ages—it was almost entirely neglected. The impure water supplies and the accumulated filth of mediæval cities produced fearful consequences in the terrible pestilences which desolated Europe.

With the revival of learning and science in the 14th and 15th centuries, attention again came to be paid to sanitary engineering; but for three or four hundred years more, little was done toward putting drainage and water supply on a scientific basis. Drains, rather than sewers, were built in the various towns as absolute necessity made imperative; but they were constructed piecemeal, and not so as to form comprehensive systems. They were not made watertight or self-cleaning; but it was usually considered necessary to make them large enough for men to enter to remove the filth, whose accumulation and festering in them were believed unavoidable.

In England, modern sanitary engineering may almost be said to have had its origin; yet so late as 1815, laws were enforced forbidding the emptying of fæcal matter into the sewers. "Such matter was generally allowed to accumulate in cesspools, either under the habitations of the people or in close proximity thereto."* In fact, though no longer enforced, these laws were not repealed until 1847, when Parliament passed an exactly contrary act, making it compulsory to pass fæcal and other similar foul matter into the sewers.

Modern sanitary engineering, especially as regards sewerage and drainage, has had almost its entire development since 1850. It was not until 1873 that there was published a comprehensive treatise on sewerage, that of Baldwin Latham, already quoted. At about this time, also, much attention began to be paid in England to sewage

*Baldwin Latham.

purification. It was reserved, however, for America to put sewage purification on the road to a satisfactory scientific solution, by the thorough investigations of the Massachusetts State Board of Health, begun in 1887 and still under way.

In America, much was done in the third quarter of the 19th century to advance sewerage engineering, through the studies of able engineers in connection with the design of systems for Chicago, Brooklyn, and other large American cities, the results being published in papers and reports, or in book form.

About 1880 the *separate* system of sewerage came strongly into prominence in America, as advocated by the late Col. Geo. E. Waring; and the construction of the Memphis (Tenn.) sewers on this system at that time, together with their great success in putting a stop to the fearful epidemics which had so often desolated that city, did much to make sewerage possible for small cities. At present, sewers have become so common and so necessary in modern life, that villages of 2,000 population, or sometimes of even less, are very generally taking up their construction.

With the present wide adoption of sewers, even by small communities, sewage disposal has come to be of very great importance, and is now undergoing great development. Many discoveries remain to be made in this line, in which the guiding principles have not yet been so thoroughly worked out as in the construction and maintenance of sewers themselves.

3. Importance and Value of Sewerage and Drainage. The importance and value of the constructions of sanitary engineering can hardly be exaggerated. Upon them absolutely depends the health of every city. One needs but to read descriptions of the great modern epidemics of yellow fever at Memphis and New Orleans, or of cholera at Hamburg, or to have been engaged to visit as sanitary engineer an American town during one of the numerous recent outbreaks of typhoid, to understand the truth of the scripture, "All that a man hath will he give for his life." Yet not only could sanitary engineering absolutely prevent every such epidemic; but, in addition, it could annually save thousands upon thousands of other lives which now succumb to bad sanitation.

Already very much has been accomplished in this direction by improved sanitation, though ideal conditions are yet seldom attained.

A prominent sanitary engineer estimated from actual statistics, that as early as 1885 there was a saving from this cause of 100,000 lives and 2,000,000 cases of sickness, annually, in Great Britain, in a total population of only 30,000,000. Figuring on the basis of the money value alone of the lives saved, and of the sickness and loss of time avoided, the money value of the above result would be almost incalculable.

In many individual cities, statistics have shown in death rates an immediate lowering, due to the construction of sanitary improvements, more than sufficient in money value to the community to pay for the entire cost. Funeral and sickness expenses saved, alone, often make enormous sums.

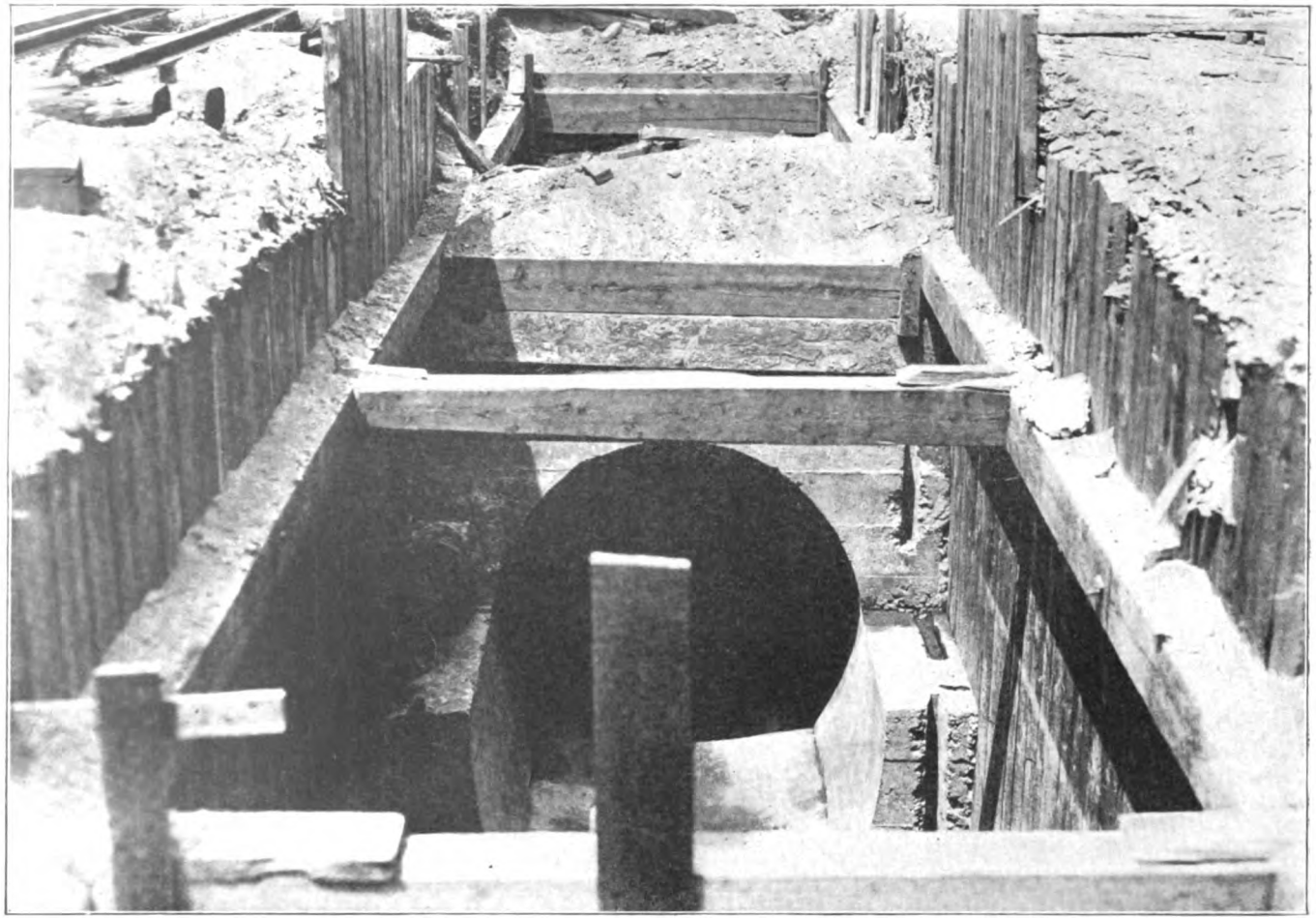
In this connection, it should be said that pure water supply and good sewerage are both essential, and that it is impossible to separate the value of one from that of the other. A polluted water supply may spread disease, no matter how perfect the sewerage, and an abundant water supply is essential to the proper working of sewers. On the other hand, without sewers and drains, an abundant water supply serves as a vehicle to enable unmentionable filth to saturate more deeply and more completely the soil under a city. Cesspools are even more dangerous than privy vaults.

In addition to direct prevention of communication of disease by unsanitary conditions, modern sewerage facilities are so great a *convenience* that this advantage alone is usually more than worth the cost. This is shown by the increased selling and rental value of premises supplied with sewerage facilities. No sooner is a partial or complete sewer system constructed in a town, than prospective buyers or renters begin to discriminate severely against property not supplied with modern sanitary conveniences; and persons looking for new locations for business ventures or residence purposes, discriminate in like manner in favor of towns having good sewerage.

So great has become the demand for sanitary conveniences, that they are now being installed in farmhouses as well as in the city. It is now possible for any farmer, at an expense of only a few hundred dollars, to have hot and cold water piped under pressure in his house, a bathroom and other plumbing fixtures, and his own sewage-disposal plant. This has already been accomplished in many cases. Such improvements, if made in accordance with correct principles, greatly

SEWER IN FILLED EMBANKMENT, BOSTON, MASSACHUSETTS

Metropolitan Sewerage System.



SECTION OF CONCRETE SEWER PIPE IN TRENCH, BROOKLINE, MASSACHUSETTS

Metropolitan Sewerage System of Boston.

better the sanitary conditions of the home; and they also prevent much disease by doing away with the exposure to inclement weather, which is so dangerous an accompaniment of the old-fashioned, barbarous, outdoor privy.

The great importance of sewerage may be realized by giving some consideration to the enormous sums of money which have already been spent for sewer systems in this country alone. Villages of 3,000 population in rural communities, often spend $50,000 or more upon a system. The city of Chicago has in recent years spent $50,000,000 in securing merely a satisfactory outlet for its sewers, without counting a dollar of the vast sums expended on the sewers themselves. In the United States, hundreds upon hundreds of millions of dollars have been invested in sewers.

SYSTEMS OF SEWERAGE

4. A *privy vault* is a receptacle, usually a mere excavation in the ground, for the reception of fæcal matter and urine. To prevent dangerous pollution of the surrounding soil and ground water, privy vaults should be lined with water-tight masonry; but this is seldom attempted, and even if attempted, is still more seldom accomplished, for it is difficult in such work to secure absolute freedom from leakage. The privy vault, frequently, is simply abandoned and covered over with earth when full, it being cheaper to change the location than to clean out the old pit.

The privy vault, with its inevitable befouling, in the immediate vicinity of the home, of earth, air, and water, the three great requisites of health, and with its danger from pneumonia and other diseases which may be contracted from exposure, should be adopted only in case of absolute impossibility to secure something better, and even then only as a temporary resort. It is not so objectionable in the country as in the city, if located far away from the well; but here the trouble is that it is usually placed too close to the well which furnishes the drinking water. In the country the leachings from hog pens, cattle yards, and manure piles frequently add to the contamination of the drinking water. It is impossible to set any safe distance at which a well may be placed from a privy, owing to the variable nature of the soil. The contamination may be carried very far in gravel

strata or rock crevices. Impervious clay confines filtration within narrower limits.

5. A *cesspool* is a receptacle for receiving and storing liquid sewage. It consists usually of an excavation dug in the ground, lined with masonry, and covered, into which the sewer from the house discharges. To prevent contamination of the surrounding soil and ground water, the cesspool should be made absolutely water-tight, and its contents should be removed whenever it becomes full.

A *leaching cesspool* is one not made water-tight. The liquid contents partly leach away into the surrounding soil, and often into sand or gravel strata, or crevices in the rock, which may carry the contamination to great distances. Owing to the offensive nature of the work of cleaning out cesspools, and to the expense thereof, cesspools as a usual thing are deliberately made not water-tight. The owner congratulates himself if he strikes a crevice in the rock or a gravel stratum which prevents his cesspool from filling up, though even a little thought will often show that he is thus directly contaminating the water vein which supplies his own or his neighbor's well. Even then he does not usually escape permanently the expense and annoyance of being forced to clean out the cesspool, for in time almost any crevice or porous stratum will clog so as to permit only partial escape of sewage.

Leaching cesspools should be absolutely prohibited by law. They are even more dangerous than the privy, for the liquid sewage in them can penetrate further into the surrounding soil than the fæcal matter of the privy vault.

The frequent effect of cesspools and privies is illustrated in Fig. 3, which does not at all exaggerate conditions very frequently found in cities and villages. Often the tearing down of old buildings, prior to the erection of new, exposes to view the rear of lots, and shows sometimes a half-dozen privies grouped within a few rods of several wells. The nose and the eye give convincing evidence of foulness in such cases; and chemical or bacterial analyses are not necessary to demonstrate the danger in using the wells; but the same dangerous conditions pass unnoticed in many other places in the same city, because not exposed to casual view. In time, the whole ground water under such a village or city becomes contaminated, and poisons wells and damp cellars and the exhalations from the ground.

6. A *dry closet* is a privy having a tight, removable receptacle in place of the vault, and provided with means for covering the contents with dry dust, ashes, or lime each time the closet is used. Usually a small shovel and a box are used to hold the dust or other absorbent material. Enough of the dry material should be used to absorb all liquids. The contents should be removed and hauled away in the tight box when it is full, to be emptied in a safe place or used for fertilizer. The dry earth closet is an improvement over the privy vault, but is not a safe or otherwise satisfactory arrangement.

7. The *pail system* is one in which the fæcal matter and urine are received in tight pails, which are removed daily, or at least every few days, by regular city employees. The pails are carried to some safe place, there emptied, and returned after disinfection. Although the pail system has been tried in America under exceptional conditions, it is entirely unsuited for use here, and is almost never employed, even in Europe, where the people will submit to the police interference necessary for satisfactory operation.

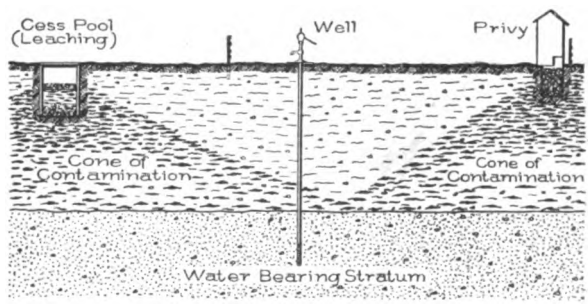


Fig. 3. Showing How Contamination of Well Water may Occur through Proximity of Cesspools and Other Sources of Filth.

8. *Pneumatic systems* of sewerage are those in which the sewage is forced through the street pipes by air, either by a partial vacuum, as in the *Liernur system* (tried in Holland), or by compressed air, as in the *Berlier system* (tried in France). Neither system is used at all in America, or to any important extent in Europe. The expense of construction and operation, and the liability of all such mechanical appliances frequently to get out of order, make them unworthy of consideration.

9. *Crematory systems* are devices for disposing of fæcal matter, urine, and garbage on the premises by drying and then burning. There are several patented methods. The matter to be disposed of is received in a furnace-like structure on the premises, built usually

of masonry, which is open to a chimney, as well as to the various closets in the building. The chimney is supposed to maintain a current of air out of the rooms in which the closets are located; this dries the material, which is then burned at intervals.

Where sewers have not been available, crematory systems have been installed in many schools and other public buildings in the United States; but, while sometimes fairly satisfactory for a while, they are usually soon found to be troublesome, expensive, and dangerous. The air-currents sometimes reverse into instead of out of the rooms containing the closets; danger ensues unless the burning is regularly attended to; and, without constant care in the attendance, the whole apparatus is likely to get out of order. Moreover, it is entirely unadapted to the disposal of liquid wastes such as those from sinks, washbowls, laundry basins, and bathtubs, which are as necessary to be taken care of as fæcal matter and urine.

In the foregoing paragraphs (Arts. 4 to 9), various makeshifts for caring for sewage have been described which are not worthy the name of "systems," although the privy vault and the cesspool are in very wide use. We next come to the only methods for removing sewage which are at present worthy of serious consideration when planning a sewerage system.

10. Water-Carriage Systems. Water-carriage systems of sewerage are those in which water is added to the fæcal matter and other foul wastes in such quantities as to permit of their rapid removal by gravity in sewers. As already stated, the water so added usually constitutes 99.8 per cent or more of the resulting sewage.

Water-carriage systems are now so universally used for sewerage purposes, that usually the two terms may be considered synonymous. That is, in the present day, a sewerage system is practically always a water-carriage system.

There are two kinds of water-carriage systems—namely, the *Combined System* and the *Separate System*.

11. Combined System. The combined system of sewerage is that in which the storm sewage flows in the same sewers with the sanitary and the manufacturing sewage. The combined system came into use prior to the separate.

12. Separate System. The separate system of sewerage is that

WATERWORKS PUMPING STATION AT ANDERSON, INDIANA

Here, in February, 1905, were carried out tests which finally demonstrated the possibility of the absolute removal from water of all disease germs of animal or vegetable origin, by means of a process using lime and sulphate of iron, with a small proportion of sulphate of copper. Over 40 cities in the United States have adopted this process for the purification of their water supply.

in which separate sewers are provided for the storm sewage and for the sanitary and manufacturing sewage.

13. Comparative Merits of Combined and Separate Systems. The separate system came into prominence about 1880. At that time and for many years following, there was an active discussion over the relative merits of the two systems, some prominent engineers advocating one, and some the other. At the present time, the discussion has died down, and sanitary engineers use both, adopting whichever is best suited to local conditions, and often using a combination of the two.

In favor of the separate system, the following points have been cited:

1. The sanitary sewage which constitutes the dry-weather flow of combined sewers is so very small in comparison with the storm sewage, that in circular sewers, which are the most economical to build, it forms merely a trickling stream, with little velocity, over the bottom of the large sewers required; while in the separate system the sewers are proportioned for this small volume, and the sewage consequently has good depth and velocity. Moreover, sanitary sewers are free from the sand and other street detritus which are inevitably washed into combined sewers during storms, and which are especially troublesome in forming deposits. Hence, in the separate system, it is easier to make sewers self-cleansing from deposits.

2. Above the low-water line in combined sewers, the extensive interior surfaces of the large sewers required become smeared with filth in times of flood, which remains to decay and produce foul gases after the flood subsides.

3. On account of the comparatively small size of the sanitary sewers of the separate system, it is easier to flush them so as to keep them clean. Automatic flush-tanks can be used at small expense to do this very satisfactorily.

4. On account of the comparatively small size of the sanitary sewers of the separate system, the air in them is much more frequently and completely changed by the daily fluctuations in the depth of sewage and by the currents of air through ordinary ventilation openings. Hence, in the separate system, ventilation is easier and more perfect.

5. In case the sewage has to be purified, the separate system is more economical, because only the sanitary sewage need be treated, the storm sewage being discharged into nearby natural watercourses.

6. In small cities, and in large portions of large cities, the storm water can usually be carried some distance in the gutters, and then removed by comparatively short lengths of storm sewers, laid at shallow depths and discharging into the nearest suitable natural watercourses. In such cases, a separate system of sewers will usually cost only a fraction, frequently only one-third, as much as a combined system. For small towns, the great cost of a combined system would often prohibit the construction of sewers entirely, or postpone it almost indefinitely, were it not that a separate system can be built so cheaply. On this account alone, the introduction of the separate system of sewers has been of incalculable benefit in America.

7. On account of their relatively small size, sewers of the separate system can be made almost entirely of vitrified sewer-pipe, which has the important advantages over brick sewers, of greater smoothness, of being impervious, of having few joints, and of ease in making the joints practically water-tight. It is impossible to make even a pipe sewer absolutely water-tight, and with brick sewers the difficulty is very much greater.

In favor of the combined system, the following allegations, corresponding to the above points, have been made:

1. By making combined sewers egg-shaped with the small end down, or by making a small, semicircular channel in the bottom (see Figs. 19, 24, and 25), the depth and velocity of the dry-weather flow can be made sufficient to cause the sewer to be self-cleansing.

2. The coating on the interior surface of large sewers above the low-water line is not dangerous, and in fact is of very little importance.

3. While it is true that the smaller, separate sewers can be flushed more perfectly for the same expense, the larger, combined sewers are more convenient for removing obstructions, and are flushed out very completely (though at too long intervals in dry weather) by the floods of storm sewage during rains.

4. In regard to ventilation, the larger volume of air over the sewage in the larger, combined sewers dilutes to a much greater degree the gases from the sewage.

5. In case the sewage must be purified, it must be remembered that the early flow of storm sewage from the streets is foul, to some extent, from the droppings of animals and other surface filth; and it may in some cases be questionable whether this may not require purification in addition to the sanitary sewage.

6. Wherever, as in the case of the business districts of large cities, it is necessary to provide as great a length of storm sewers as of sanitary sewers, it will be cheaper to build one set of sewers, as in the combined system, rather than two, as would be required in such districts with the separate system.

The *general conclusions of sanitary engineers* at present regarding the relative merits of the separate and combined systems, are as follows:

a. Either system can be made satisfactory from a sanitary point of view.

b. The cost of a properly designed system, including means for safe disposal of sewage, should ordinarily decide which of the two systems should be built.

c. On the basis of cost, the separate system is usually the better for small cities, for suburban and sometimes residence districts of large cities, and for all cases, even those of large cities, where the sanitary sewage requires treatment while the storm sewage can be safely discharged into nearby watercourses. The separate system has just been recommended for the city of Baltimore on this last account.

d. Similarly, on the basis of cost, the combined system is usually the best for the business and other very thickly built-up districts of large cities, and, in general, where storm sewers must be coextensive with sanitary sewers; also for cases where both storm sewage and sanitary sewage require purification.

e. Often a combination of the two systems can be made to advantage, storm water being admitted to the sewers only in certain portions of the system, such as the business districts.

GENERAL FEATURES OF SEWERS

14. Kinds of Sewers. *Sanitary sewers* are those constructed to carry foul waste liquids of human or animal origin—that is, sanitary sewage. Since sewage of human or animal origin is most apt to contain the germs of human diseases, sanitary sewers require special

precautions in design, construction, and maintenance, to render them safe. Manufacturing sewage is often, however, even stronger and more offensive than sanitary sewage, and hence requires equal precautions. In the separate system, the manufacturing sewage should go into the sanitary sewers or into special sewers of similar character.

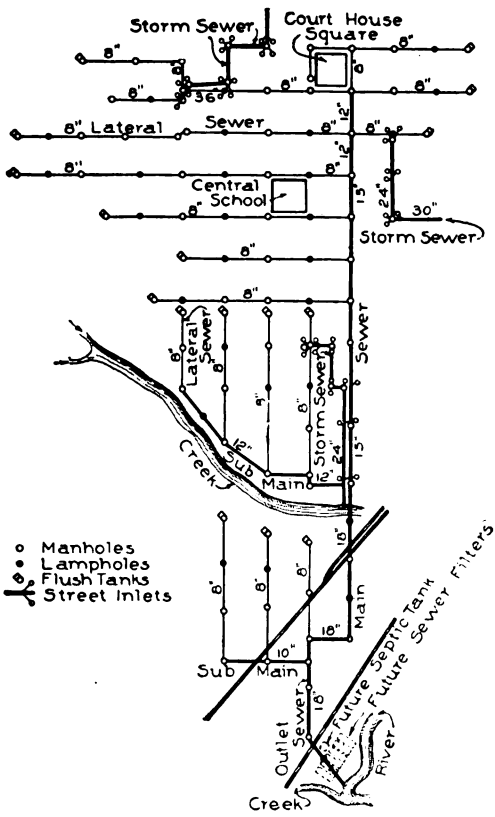


Fig. 4. Kinds of Sewers and Arrangement of Accessories.

Combined sewers are those constructed to carry both sanitary sewage and storm sewage. With the combined system, the manufacturing sewage also usually goes into the combined sewers.

Storm sewers are those constructed to carry storm sewage only.

An *outlet sewer* is one connecting a sewer system, or a part thereof, with the point of final discharge of the sewage.

A *main sewer*, or *sewer main*, is the principal sewer of a city, or of a large district thereof, into which branch sewers discharge.

A *sub-main sewer* is a branch of a main sewer, receiving in its turn the discharge of smaller branches.

A *lateral sewer* is one not receiving the discharge of other sewers, hence serving only property closely adjacent.

In Fig. 4, the various kinds of sewers above described are shown, from a portion of the actual sewerage map of a small city, sewered on the separate system.

15. *Intercepting sewers* are those built across lines of other

CURVE IN CHICAGO DRAINAGE CANAL NEAR ROMEO, ILLINOIS

The white streak along the bank is all stone excavated from the channel. The limestone taken out in the construction of this waterway, which is practically a 25-mile extension of the harbor of Chicago, has a market value, for concreting, paving, etc., of about $30,000,000.

sewers, to intercept the sewage flowing in them and carry it away to different outlets.

In Fig. 5 are shown the intercepting sewers of the city of Chicago, built along the lake front to intercept the sewage in the sewers which formerly discharged into and polluted Lake Michigan, from which the water supply of the city is taken. From the intercepting sewers, the sewage is pumped into the Chicago River, which now discharges through the great Drainage Canal into the Desplaines river, the Illinois River, the Mississippi River, and the Gulf of Mexico.

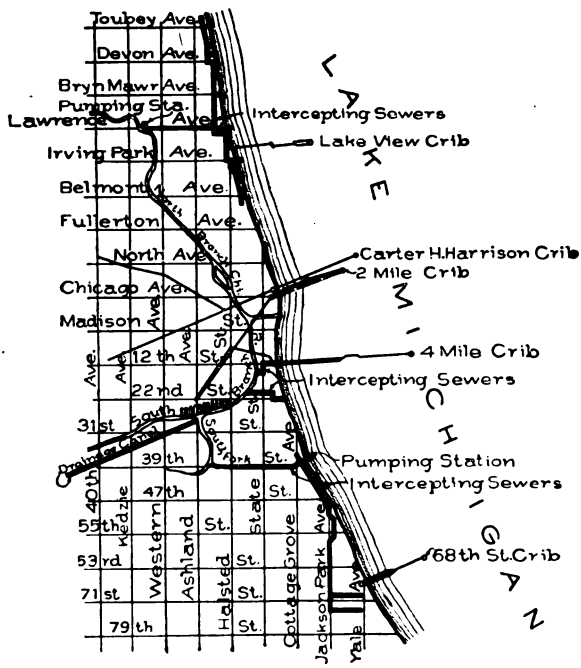


Fig. 5. Intercepting Sewers of the City of Chicago, Ill.

16. General Description of Sewers. Sewers, as usually built, are smooth pipe or masonry conduits, as nearly water-tight as practicable, buried in the ground as deeply as necessary to serve the adjacent houses and drain other territory tributary upstream. They are very carefully constructed to an exact grade line, determined by the engineer who made the sewer plans.

Unless special circumstances require other forms, sewers are usually made circular, this shape giving the greatest strength and area for a given amount of material. For other shapes, and the circumstances to which they are adapted, see Figs. 19 to 25.

The *invert* of a sewer is the lowest point on the interior surface (being so called because the interior curve is there inverted). When the grade of a sewer is mentioned, or the elevation of the sewer at a

given place is spoken of, the invert is always meant. The invert is also sometimes called the *flow line*.

Almost all sewers up to 24 inches' diameter, and many from 24 to 36 inches' diameter, are made of vitrified or cement pipe. Above these sizes, concrete or brick masonry is ordinarily used. Stone masonry and iron pipe are also used, but only seldom. A comparison of these materials is given elsewhere in this paper.

At intervals along sewers, *manholes* (Art. 21) and *lampholes* (Art. 22) are placed to permit examination and repairs, and often *flush-tanks* (Art. 23) are provided to keep the sewers clean. In the case of storm sewers and combined sewers, either *street inlets* or *catch-*

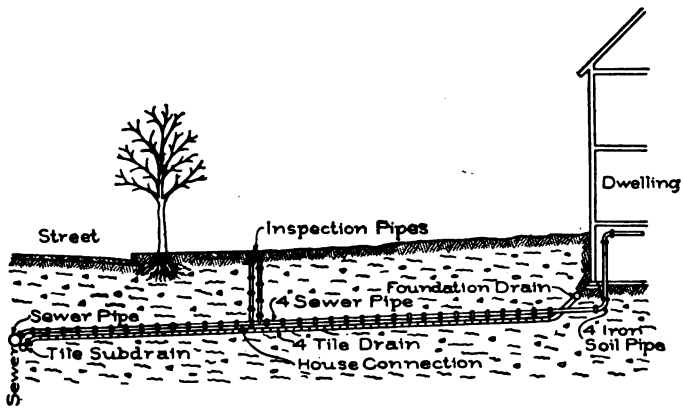


Fig. 6. Street Sewer, Subdrain, and House Connection.

basins (Art. 27) must be provided, for admitting the storm water to the sewers. These are usually placed at or near the curb corners at the street intersections.

A general idea of the relation of a sewer to a building served by it, may be gained from Fig. 6. The sewer there shown is a pipe sewer. Usually all lateral sewers are made of pipe; and in the separate system, the submains and mains also, unless the city is quite large.

17. Location of Sewers. Sanitary sewers are usually placed on the center lines of the streets, so as to give equal fall from the houses on both sides. On this account, water, gas, and heating mains, storm sewers, and other conduits should be constructed far enough from the center lines not to interfere with the sanitary sewers. Not

infrequently the center of the street is found already occupied by other conduits which were located without proper foresight; and it is then necessary to place the sewer nearer to one side than the other.

In cases of streets on side hills, it is sometimes necessary to place the sewer close to the downhill side of the street, in order to serve houses on that side which are lower than the street grades.

In a few cases of excessively wide avenues, especially if paved, it is cheaper to build two lines of sanitary sewers, one on each side, than to construct the longer house connections required.

In any town having a fairly extensive system of alleys, careful consideration should be given by the sewerage engineer to the feasibility and desirability of locating part or all of the sanitary sewers in them instead of in the street. In Memphis, this plan was followed as far as practicable. It is not usually feasible to locate combined or storm sewers in alleys, because such sewers must receive storm water from the streets running in both directions, and hence must usually have the street inlets placed at the street corners.

Streets vs. Alleys for Sanitary Sewers. Location of the sanitary sewers in the alleys has a great advantage in avoiding the tearing up of the streets and pavements for sewer repairs and for new house connections, which not infrequently causes them serious injury. Pavements are often ruined by the trenches dug for water, sewer, gas, and other connections. Also, if the sewers are in the alleys, the trenches for house connections do not cross the lawns in front of the houses.

On the other hand, the system of alleys in the ordinary town is a public nuisance. They are usually filled mainly with manure piles, garbage, and debris of all descriptions; and they open through the middle of the blocks vistas which suggest most forcibly a neglected city dumping ground. Owing to their vile sanitary condition, the alleys are usually the first danger spots demanding attention when a town is threatened with an epidemic. Except in the business districts where they can be paved and policed, there is no necessity for alleys unless the lots are very narrow, for in almost every town there are sections which do without and never miss them. Teams can without inconvenience drive in from the front, along a cinder or gravel drive. Such sections are better off without the alleys, from both the sanitary and the æsthetic points of view.

For the above reasons, it is often unwise to perpetuate, or perhaps even extend, the alley system by locating sewers in them.

Again, the system of alleys, more often than not, is far from being as complete as the street system; and in such cases it will usually add considerably to the total length of sewers required to serve a given territory, if part of them are placed in the alleys. The alleys, also, are usually too narrow to permit the construction of sewers of considerable depth, without trouble as regards the excavated material, the handling of pipe, etc. Moreover, houses and the fixtures in them are usually so located that the house connection would be longer to the alley than to the street, requiring a deeper sewer for equal service. This, however, is not always the case.

The sanitary engineer should study each town by itself, and decide this question after giving due weight to all these various considerations.

18. Depth of Sewers: The depth of sanitary and combined sewers should be great enough to afford good drainage to the basements of all buildings. This will usually call for the tops of the sewers to be about 3½ feet below the basement floors, as follows:

MINIMUM DEPTHS FOR SANITARY AND COMBINED SEWERS

Fall from sewer to house	2 ft. 0 in.
Fall from basement floor to house connection	1 ft. 6 in.
Total from *top* of sewer to basement floor	3 ft. 6 in.
For *sewer laterals*, add to the above for fall at sewer	1 ft. 0 in.
Total from *invert of lateral sewer* to basement floor	4 ft. 6 in.
For *residence districts*, add for ordinary-depth basements below street level	4 ft. 0 in.
Total minimum depth to invert of *lateral sewers in residence districts*	8 ft. 6 in.
For business districts, add for ordinary-depth basements	4 ft. 0 in.
Total minimum depth to invert of *lateral sewers in business districts*	12 ft. 6 in.

Hence, under average conditions, the depth of sanitary and combined pipe sewers of 12-inch diameter and less, should be not less than 8½ feet in residence districts, and 12½ feet in business districts. If, however, there is only a short stretch of low-lying ground on a residence street, it may be advisable to reduce the above depth, say to 6 feet as a minimun, when by so doing a very long stretch of sewer can be lessened that much in depth throughout, and a large saving in cost made thereby.

In the case of sanitary and combined sewers more than 12 inches in height, the above depths should be increased by the excess over 12 inches, for the house connections should enter near the top of the sewer.

In the case of storm sewers and of outlet and intercepting sewers, the depth will no longer be determined by the depth of basements alongside. In these sewers three other considerations determine the depth: (1) the depth at the upper end necessary to afford a good outlet for the sewage; (2) the grade necessary to give good velocity; (3) the depth necessary to prevent injurious heaving of the sewer foundations by frost.

In regard to the third point, no danger need be apprehended of the sewer itself freezing up, even if it be laid practically at the surface, for a stream of warm, flowing sewage will not freeze. There will be little or no danger of trouble from heaving, if the sewer foundation be four feet under ground; and many stretches of pipe sewers only two or three feet deep operate with entire satisfaction even in the northern United States.

19. Subdrains. It has already been stated that sewers should be made as nearly water-tight as possible. Otherwise there would be danger of the sewage leaking out so as to contaminate the adjacent soil. Hence, while it is not possible at any reasonable expense to make sewers *absolutely* tight, they should be built with the utmost care in this particular.

Yet, when due care is used in this respect, the sewer is made unfit for performing another important duty—that of draining away subsoil water so as to dry out unwholesome dampness from the soil, and especially from wet cellars and from under and around houses built on low ground.

In order to secure such drainage, and also, in case of wet ditches, to help remove water from the trenches during construction, it often becomes necessary or advisable to add to the sewer a *subdrain*.

A *subdrain* is a line of drain tile or sewer pipe laid with open joints, in the same trench with the sewer.

To allow connections with cellar drains to be made from both sides of the streets, the subdrain should be placed with its top a few inches below the bottom of the sewer; and to leave a firm foundation

for the sewer itself, the subdrain should be placed a little to one side of the sewer.

With the above arrangement, special care should be taken to make the sewer joints tight, and there is some danger of slight leakage of sewage into the subdrain. Such leaks tend to stop themselves as time passes.

It is not safe to connect cellar drains directly with a sewer, even though they are trapped to prevent the sewer air from penetrating into and filling the pores of the soil under houses. In dry times, there may be no water running in the cellar drains; and at such times the water in a trap may evaporate so as to unseal it. Cellar and foundation drains should be connected to the subdrain instead of to the sewer itself.

The general relation of the subdrain to the sewer in the street, and the method of connecting it with the foundation drains, may be seen in Fig. 6.

In construction, the joints of the subdrain should usually be wrapped with muslin to prevent the entrance of mud and sand. The cloth, of course, does not last long; but by the time it rots, the soil around the tile will usually have become recompacted so that there is no longer danger of its getting into the drain. In quicksand, it may sometimes be necessary to fill in fine pebbles or broken stone around the subdrain.

20. House Connections. In Fig. 6 is also shown the method of connecting the sewer itself with the iron soil-pipe which drains the different plumbing fixtures, and which should extend at least 6 feet outside the basement wall. The house connection should be a line of 4-inch vitrified sewer-pipe, laid at right angles to the sewer, with tightly cemented joints, and if possible to at least a 2 per cent grade (that is, with a fall of 2 feet in 100 feet length). Some prefer 6-inch house connections; but these should not be allowed with 8-inch sewers, as the house connection may then allow obstructions to be carried to the street sewer large enough to catch therein and cause stoppages. At the sewer, the house connecton should turn down, by a 4-inch 45-degree elbow, into a 4-inch Y-junction laid so as to slant upward 45 degrees—all as shown in Fig. 7. This slant upward

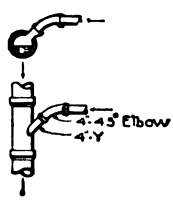


Fig. 7. Junction of House Connection with Sewer.

keeps the Y from affecting the smooth ordinary flow in the sewer.

In case the sewer is more than 12 feet deep below the street surface, the expense of digging down to it in making house connections would be so great that it is usually better, while the trench is open during sewer construction, to put in a *deep-cut house connection*, as shown in Fig. 8. In this case, sewer pipe must be used from the subdrain also, if such a drain is used; and care should be taken to turn the bells of the subdrain connection down so that the plumbers need make no mistake in the connections afterwards.

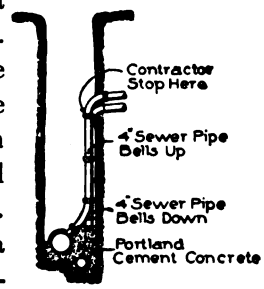


Fig. 8. Deep-Cut House Connection.

In sewer construction, a Y-junction for a house connection (or a deep-cut house connection, if the sewer is over 12 feet deep), should be conveniently located opposite each lot on each side of the sewer; and the ends should be stopped with vitrified stoppers, covered over with sand and then cemented in. Full and accurate records must be kept of the exact locations of these connections, so that they can be found without trouble at any time.

No person should be allowed to cut or break into a pipe sewer for making house connections or any other kind of junction. If there is no Y or T-branch already set for the connection, a full length of pipe should be broken out and the proper Y or T-branch inserted. A skilful workman can readily do this by breaking off one-half the bell of the new pipe, and of that of the old piece into which it must be inserted, and turning the new piece half around after insertion. The joints must then be re-cemented with great care.

21. Manholes. It has already been stated (Art. 16) that manholes must be placed at intervals along sewers, to permit of examination and repairs. These manholes are usually circular brick wells, with Portland cement concrete bottoms and heavy cast-iron covers, as shown in detail in Fig. 9. They must be large enough at the bottom, and for a couple of feet above the top of a pipe sewer, to permit a man to work comfortably. Four feet in diameter is a satisfactory size. Sometimes the manholes are made elliptical at the bottom, with the long axis lengthwise of the sewer; but this form is more difficult to build. Above the point mentioned, the sewer may be drawn in gradually to a diameter of about 2 feet 9 inches, at a point

2 feet 9 inches below the street surface, and thence narrowed more rapidly to about 20 inches diameter at the bottom of the cover casting.

The cover casting may be of any manufacturer's design satisfactory to the engineer, weighing at least 375 lbs. The lid should usually be perforated with 1-inch holes, to permit ventilation of the sewer; and immediately below it, there should be hung a heavy cast-iron *dustpan*, to catch any dirt entering through the perforations.

There should be a ladder of iron rungs built into the walls, as shown in Fig. 9.

The channels in the concrete bottom should be very carefully formed to give smooth, true, circular channels. They are sometimes lined with split sewer pipe. The benches at the sides of the channels should slope down towards the channels, as shown in the figure.

The concrete for the bottom may be made of 1 part Portland cement, 3 parts sand, and 5 parts of broken stone. All the brickwork should be laid with tight *shove joints*, in 1-to-3 Portland cement mortar; and the manhole walls should be plastered both inside and outside with 1-to-2 Portland cement mortar.

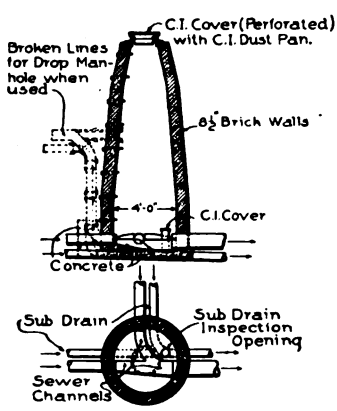
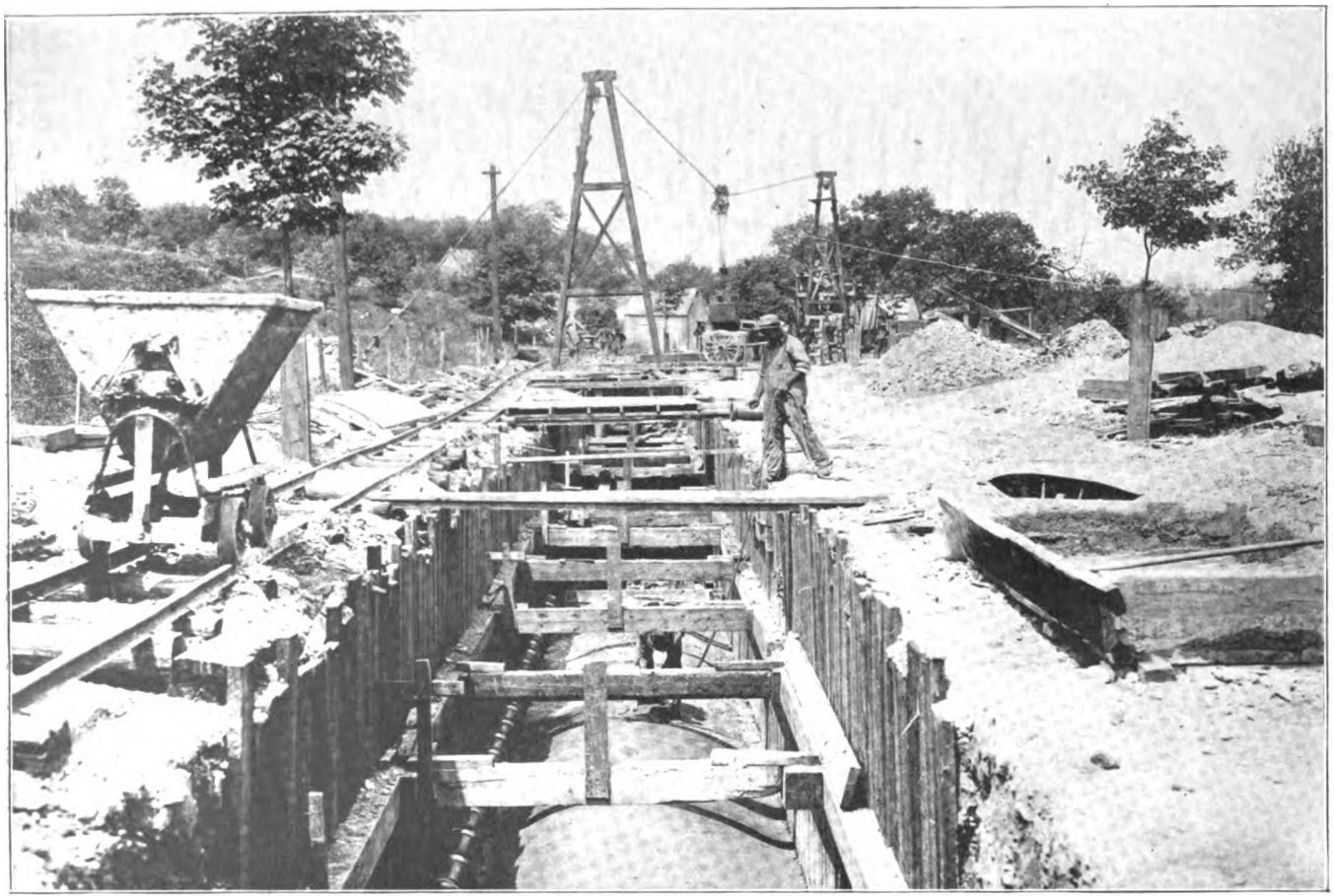


Fig. 9. Sectional Elevation and Plan of Sewer Manhole.

Should sudden drops in the sewer be desirable, they can be made at *drop manholes*, in the manner shown by the broken lines of Fig. 9.

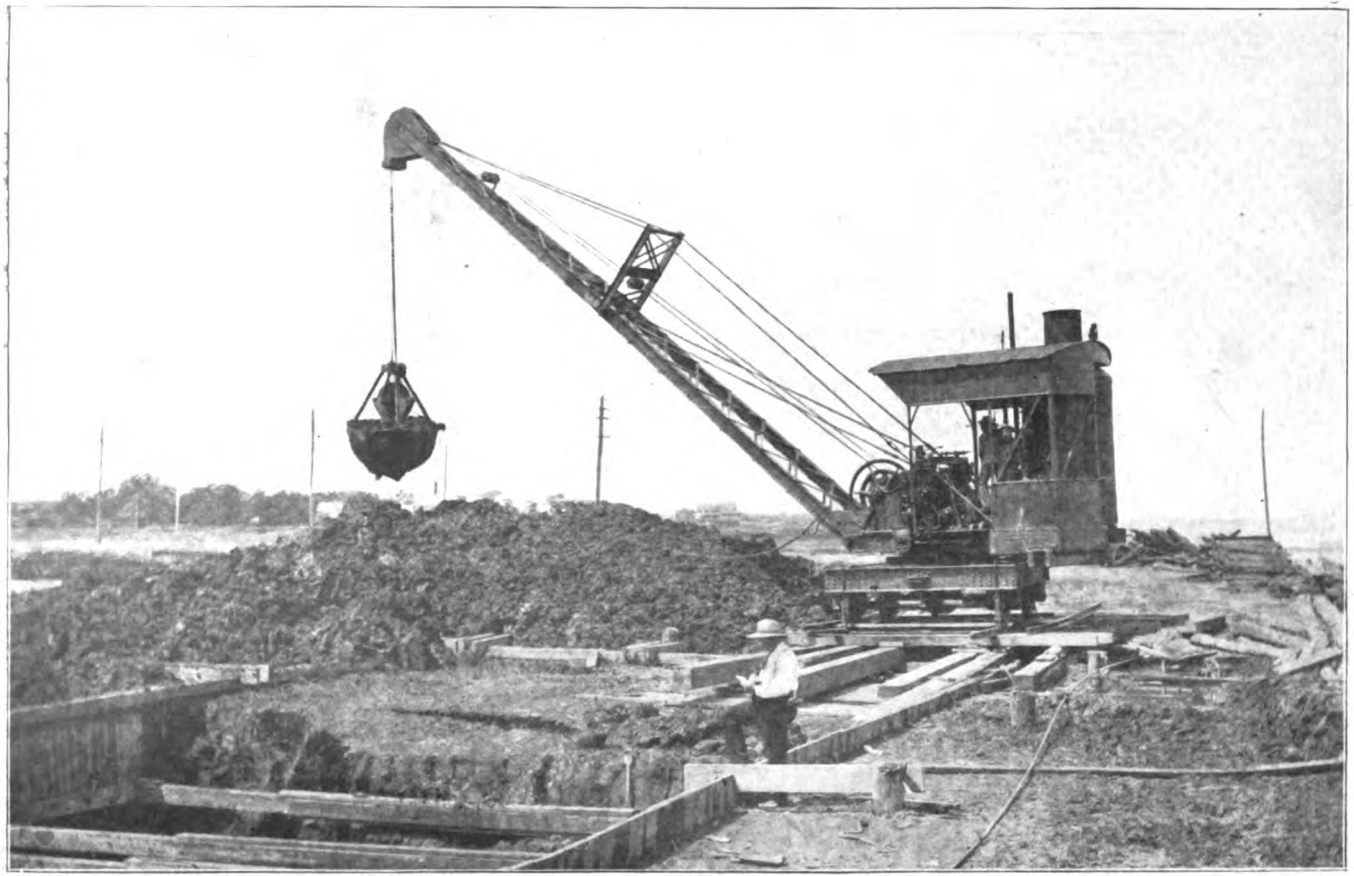
In the case of large masonry sewers, which often are many feet in diameter, the manholes may be joined directly to the masonry of the upper part of the sewer.

Opinions of sanitary engineers differ somewhat as to the distance apart at which manholes should be placed. In general, a manhole should be placed at all junctions of sewers, and at every change of grade or alignment in all sewers but those large enough to be entered readily for cleaning. This means that sewers should ordinarily be perfectly straight between manholes, to facilitate inspection and repairs, all changes in both grade and alignment being made at the manholes themselves.



SEWER TRENCH IN BROOKLINE, MASSACHUSETTS

Metropolitan Sewerage System of Boston.



LOCOMOTIVE CRANE USED IN SEWER TRENCH CONSTRUCTION

Metropolitan Water and Sewerage System of Boston, Mass.

Also, in any part of the system—such as in the business district—where it is especially objectionable to have the street dug up for repairs, manholes should be placed at least as often as every city block—that is, 300 to 400 feet apart. In the other parts of the system, some engineers leave out every other manhole where the grade and alignment are straight, putting manholes at least every two blocks. The intermediate manholes left out are replaced by *lampholes* (Art. 22) to save cost. In Figs. 4 and 38, the above arrangement of manholes is shown in two actual sewer systems.

22. Lampholes. The lampholes which, to save cost, are sometimes adopted in place of part of the manholes, consist each of a vertical line of sewer pipe, with cemented joints, reaching to the street surface, as in Fig. 10. Usually 8 inches is the minimum diameter for this pipe, which is cemented at the bottom into a regular sewer-pipe T-junction. Some concrete should be placed under and around this tee for a foundation. At the street surface, there should be an iron casting similar to a manhole casting, but smaller, as shown in Fig. 10.

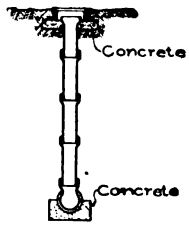


Fig. 10. Lamphole.

The earth, in refilling, needs to be very thoroughly tamped around the lamphole; and the lamphole casting should not be set until the material is thoroughly settled.

The object of the lamphole is to permit of inspection of the sewer, in determining whether it is clean and in locating stoppages. While its name suggests the lowering into it of a lamp, a beam of sunlight reflected into it from a mirror is more convenient.

A lamphole usually costs about $30 to $35 less than a manhole.

In Figs. 4 and 38 the above arrangement of lampholes in two actual sewer systems may be seen.

23. Flush-Tanks. Near the upper ends of sewers the flow of sewage is very small, sufficient only to make a shallow, trickling stream, liable not to be able to carry along the solid matter in the sewage so as to prevent deposits. An 8-inch lateral sewer in a residence district in a small town, even if laid at the minimum grade, would usually have an average depth of flow in the upper two and one-half blocks of less than one inch. Hence it is desirable, though not always absolutely necessary, to provide some special means for

regularly flushing the upper portions of sewer laterals, to make them self-cleansing.

Again, in low-lying, level districts, it may be necessary, on account of the lack of fall, to lay the sewers at such slight grades that the velocity is insufficient to prevent deposits. Here, too, some special means should be provided for regularly flushing the sewers.

In the case of pipe sewers, such as are ordinarily used for the laterals in all systems, and for most of the mains in separate systems,

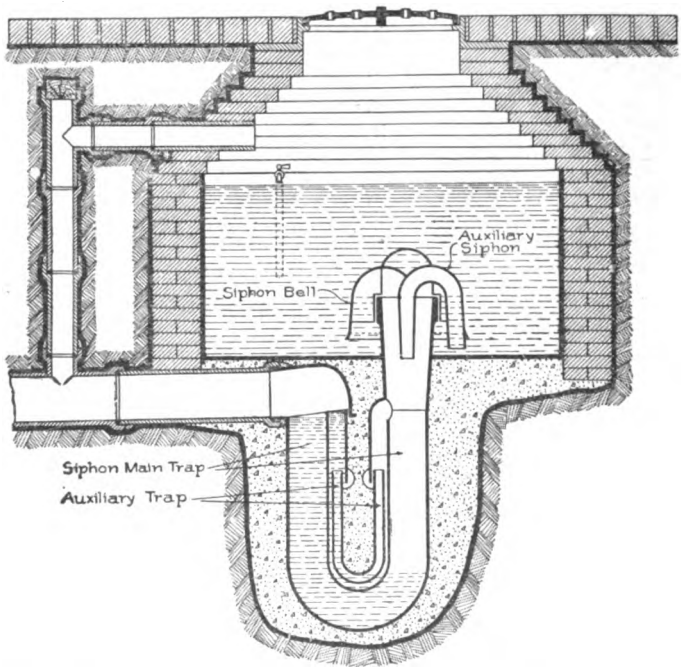


Fig. 11. Sewer Flush-Tank with "De La Hunt" Adjustable Siphon.

the most efficient and reliable means for securing regular flushing is the use of automatic flush-tanks.

A *flush-tank* is a masonry cistern built in the street, above the grade of the sewer, filled by a constantly running stream of water brought by a small pipe from the water-supply mains, and suddenly emptied by automatic devices into the sewer whenever the high-water line is reached.

Flush-tanks usually have a capacity of 150 to 500 gallons, and should approach the larger size named, to secure an efficient flush

for two or three blocks. When made separate from manholes, flush-tanks are usually circular and of the general design of the masonry tank shown in Fig. 11. It is usually better, however, to combine the flush-tank with a manhole, as is shown by the masonry tank and manhole in Fig. 12. This permits inspection of the flush-tank and sewer, and is cheaper than to build manhole and flush-tank separate.

The bottoms of flush-tanks are usually of Portland cement concrete, and the walls of brick laid in Portland cement mortar. The

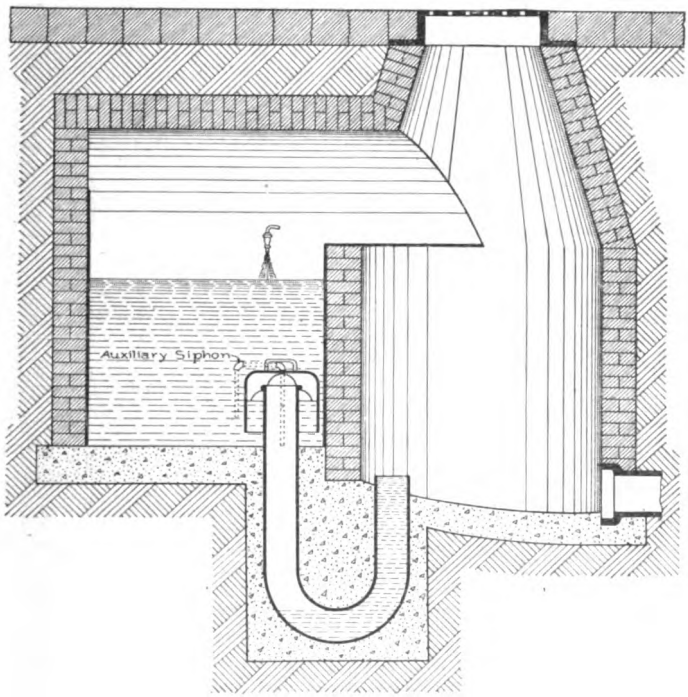


Fig. 12. Combined Flush-Tank and Manhole with Special "Miller" Siphon.

tanks should be plastered inside and outside as described for manholes (see Art. 21). Special care should be used to make flush-tanks absolutely water-tight.

The water is usually brought to the flush-tank by a ¾-inch galvanized pipe from the nearest water main. This pipe must be laid below the frost line (5½ to 7 feet deep, in the northern part of the United States), but should be turned up after it enters the flush-tank so as to discharge above the high-water line, as shown in Fig. 11.

The flush-tank may be prevented from freezing by being connected with the sewer above the high-water line, as shown in Figs. 11 and 12, so as to admit the warm air from the sewer.

It is a quite common practice to place flush-tanks at the heads of all laterals, as illustrated in Figs. 4 and 38. While some engineers dispute the necessity for this, it must be admitted that such an arrangement will be of great benefit, and its adoption is here advised for most cases.

In Fig. 38 the use of flush-tanks is shown at certain half-way points on the long laterals. The necessity for this arose from the fact that the sewers were not to be completed to the north ends of the laterals for some years after the southern portions were built.

The writer of this paper has used flush-tanks with success and great benefit, at intervals of about two or three blocks on sewers laid at grades below those considered necessary to make the sewers self-cleansing, though part of the flush from the intermediate tanks flows some distance upstream at each discharge.

The flush-tanks of a sewer system should be frequently inspected after the sewers are put into operation, and should be carefully kept in working order. The things needing most faithful watching are: first, the automatic discharging apparatus; and, second, the supply of water. The faucet admitting water may readily become choked up, putting the flush-tank out of service, or, on the other hand, may get wide open, wasting thousands of gallons of water every day.

24. Automatic Flushing Siphons. The reliability of flush-tanks in actual use will depend upon the frequency and care with which they are inspected and kept in working order, and especially on the reliability of the automatic discharging apparatus. No discharging apparatus having moving parts should be used in flush-tanks. Such apparatus is too likely to get out of order.

In Figs. 11 and 12, *sewer siphons* are shown for automatically discharging the flush-tanks suddenly whenever they fill to the high-water line. Such siphons have no moving parts whatever to get out of order, and should always be employed with flush-tanks.

In Fig. 11 the four ordinary parts of a flushing siphon are indicated. All four are usually iron castings, and must be air-tight. The *siphon bell* rests upon the *main trap*, which latter, together with the *auxiliary trap*, must be filled with water to the heights of the

short legs, before the bell is placed in position. The main trap must be set plumb. The *auxiliary siphon* serves to ensure, at the end of the discharge, the *venting* of the siphon—that is, the free admission of air to the inside of the bell. With clear water, the auxiliary siphon is not always used; but it should be used whenever the siphon is to be used with raw sewage.

In the working of the siphon, the water in the flush-tank confines the air inside the bell and above the water in the main and auxiliary traps, and puts it under increasing pressure as the water rises. When the high-water line in the flush-tank is reached, this pressure becomes so great that the water in the auxiliary trap is forced down to the very bottom of the trap, and the confined air then blows out of the short leg of the auxiliary trap, thus releasing the air-pressure inside the bell, which up to this time has held back the water in the flush-tank. The water in the flush-tank then rushes out into the sewer through the main trap, and by siphonic action will continue to flow out until drawn down to the level of the bottom of the bell. Air then enters the bell through a small *sniff-hole* provided near the bottom of the bell for this purpose, *breaking* the siphonic action—that is, *venting* the siphon.

In case a siphon is used for raw sewage, there is often difficulty in securing satisfactory venting of the siphon at the close of the discharge; but this trouble can be remedied by using an *auxiliary siphon*, as shown in Fig. 11, and as illustrated by broken lines for the "Miller" siphon in Fig. 12.

In the *Miller siphon*, shown in Fig. 12, there is no auxiliary trap; but at high-water line the air-pressure in the main trap becomes so great that a bubble escapes, taking with it enough water from the short leg to start a sudden rush of water from the tank into the main trap, which suffices to establish siphonic action. This greatly simplifies the siphon; and the principle can be relied upon for siphons not larger than about eight inches internal diameter of the main trap. Larger siphons should have auxiliary traps.

In some siphons—as, for example, the *Rhoads-Miller*—the auxiliary trap is cast as a part of the main trap, out of which it opens below the floor of the tank, being entirely buried out of sight and reach in concrete. An objection to auxiliary traps such as shown in Fig. 11, is that they are inaccessible and may in time become

stopped up. However, they make the action of large siphons more certain.

25. Hand-Flushing of Sewers. For large sewers, flush-tanks and siphons would have to be extremely large to be effective. Even in small sewers the effect of the flush will not be great for many blocks below the tank. Some engineers doubt the necessity for very extensive use of flush-tanks. When flush-tanks are not properly inspected and regulated (as to the feed faucet), they sometimes waste great quantities of city water. For these reasons, and sometimes to save cost, hand methods are sometimes relied upon for flushing sewers.

The most convenient, economical, and effective hand-flushing device is a connection with a water main by a water pipe of size large enough to flush the sewer very thoroughly. The only labor then required is that necessary for opening and closing the valves on this pipe. Such a flush, continuing much longer than the discharge of a flush-tank, can be made effective through a long stretch of sewer. The objections are the trouble and the danger of neglect inherent in hand work, and the usual greater length of time between flushings. To flush the sewers daily would be very expensive, both as to labor and as to the large amount of water needed.

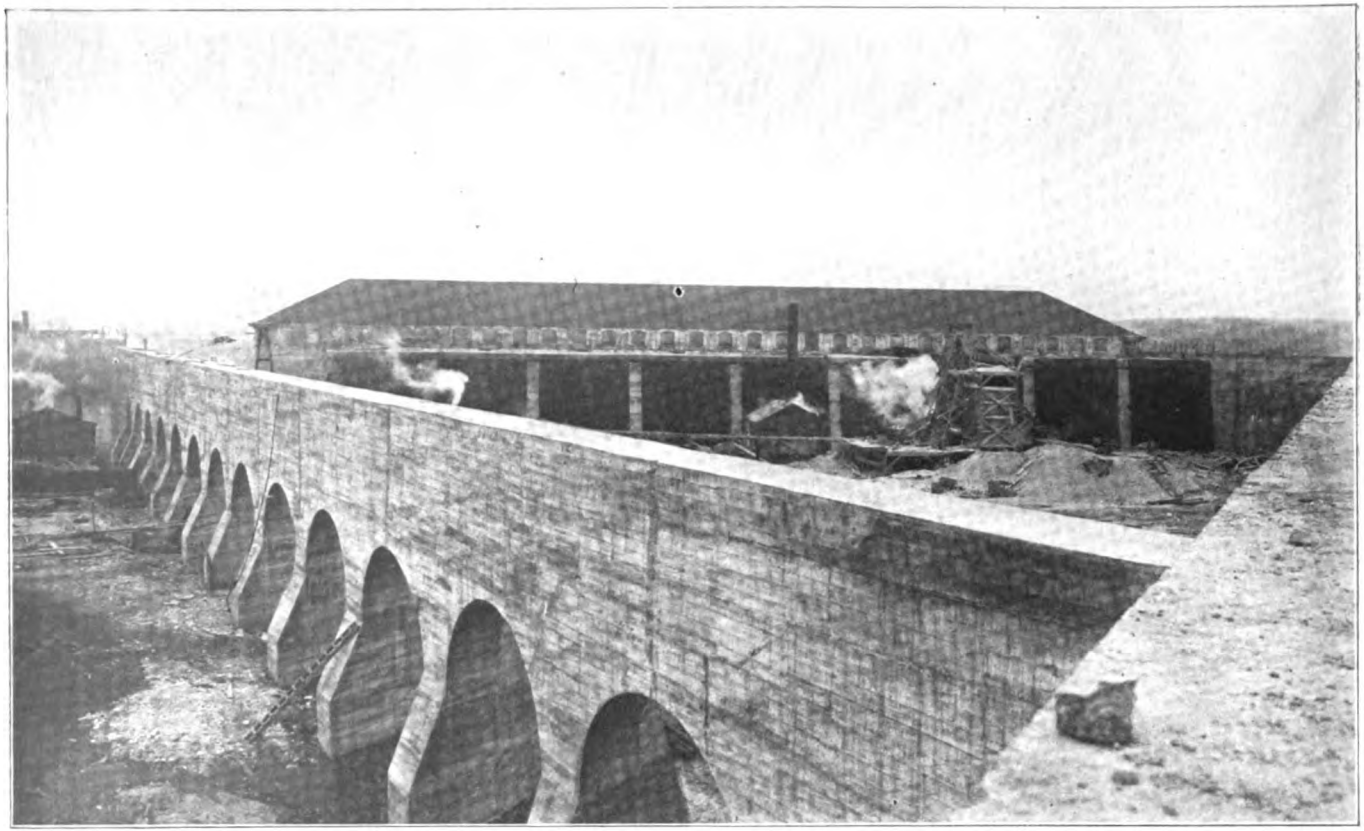
Occasionally, very favorable local circumstances may permit of the admission at will of large volumes of water for flushing purposes from a stream or lake higher than the sewer.

In some cases, hand-flushing is done by temporarily damming up the sewage itself, and then suddenly releasing it when sufficient head has been secured.

A fire hose run to a manhole from a nearby hydrant may be the resort in other cases. In extreme cases, water has even been hauled to the sewer in tanks, for flushing.

26. Sewer Ventilation. More fear used to be felt of the danger of *sewer gas* (more properly termed *sewer air*, see Art. 1) in communicating disease, than medical knowledge warrants at the present time. Nevertheless, it is very important, not only from the sanitary but from many other points of view, that sewer air should be as pure as possible; and this requires good ventilation of the sewers. Fresh-air currents in the sewers should be maintained in some reliable way.

One method of securing this is to use perforated manhole covers (see Fig. 9). Objection is sometimes made to these as letting objec-



POWER HOUSE ON CHICAGO DRAINAGE CANAL AT LOCKPORT, ILLINOIS

Power House in background; in front of it is the forebay, with screens protecting the conduits leading to the turbine chambers; in foreground is the arched concrete fender wall.

Courtesy of R. Isham Randolph.

ROAD-BUILDING IN PORTO RICO

Stretch of finished road south of Adjuntas. Paved gutter shown at right.

tionable odors out into the street; but with well-designed and well-constructed sewers, well flushed and well ventilated, there will be no cause for complaint. If there are seriously objectionable odors from the manholes, such odors should be considered valuable as notices that the sewers are in dangerous condition, demanding immediate work to make them safe. Sewer air escaping into streets through manhole-cover perforations, is at once so diluted by fresh air as not to be dangerous to the health of passers by.

Another effective means for securing good ventilation is to extend the cast-iron soil-pipes (which form the main drainage pipes in the plumbing systems of houses) untrapped and full size through the roof. Figs. 4 and 35 show the omission of traps on the soil pipe. In Fig. 35, however, the use of a *disconnecting trap*, to disconnect the sewer air from that in the house plumbing pipes, is shown by broken lines. In case this is used, a ventilating pipe for the sewer should be extended up the sides of the house from the sewer side of the trap, and a fresh-air inlet provided on the house side, both as shown by the broken lines in Fig. 35.

The use of perforated manhole covers and untrapped soil pipes extending through the roofs, is all that is required to secure good ventilation of the sewers, the house connections, and the soil pipes themselves. Their use provides a large number of openings at different levels; and the temperature of the air in the sewers is practically always different from that above the ground. Hence air-currents are maintained for the same reason that chimneys cause draughts for fires, and a good circulation of air is maintained.

In the past, experiments in sewer ventilation have been made with tall chimneys, fan blowers, etc.; but such devices are entirely unnecessary, are very costly, and are usually unsuccessful on account of the very large number of openings into the sewer, which limit the air-currents produced by such devices to short distances.

27. Street Inlets and Catch-Basins. In the case of storm sewers and combined sewers, means must be provided for admitting the storm water to the sewers from the streets. For this purpose, either *street inlets*, as shown in Fig. 13, or *catch-basins*, as shown in Fig. 14, may be used. If the water can be allowed to flow one block safely in the surface gutters, the inlets for storm water would need to be only at each street intersection. In a few cases they need to be

closer; but in many more cases the storm water can be carried in the gutters for two or even a greater number of blocks without injury, thus greatly reducing the number and cost of storm sewers and of inlets for storm water.

The simplest and least expensive arrangement for admitting storm water is the *street inlet*, which, as shown in Fig. 13, is a mere branch sewer, with a grated opening from the street. Besides costing less, the street inlet is often preferred for sanitary reasons, as it does not retain foul, unsanitary deposits, as does the catch-basin.

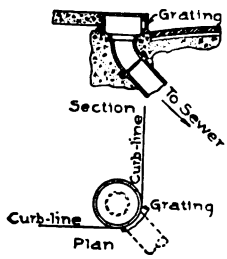


Fig. 13. Street Inlet.

The *catch-basin*, shown in Fig. 14, is designed to catch the sand, dirt, and other heavy street detritus, and prevent their entering the sewer. Unless catch-basins are frequently cleaned, however (which is very seldom the case), they fail almost entirely in this; and as they are usually well filled with more or less foul deposits, they are condemned by many engineers.

When street inlets and catch-basins are left untrapped, as shown in Figs. 13 and 14, they assist in the ventilation of the sewers. This is sometimes objected to on account of the opportunity for the escape of foul odors, and traps are introduced in both, as shown by the dotted lines in Fig. 14, to prevent ventilation of the sewers through the storm inlets. If the sewers are kept in as good condition as they should be, there will be no good ground for such objections.

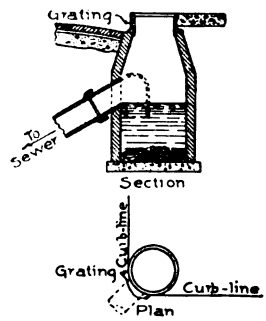


Fig. 14. Catch-Basin.

28. Inverted Siphons. It sometimes becomes necessary or desirable to carry a sewer down below the regular grade line, to pass under some obstacle or depression, and to raise it again to the regular grade line beyond. Such a stretch of sewer will necessarily flow full and be under some pressure. It is called an *inverted siphon*. The necessity for the use of the inverted siphon may be occasioned by some stream, by railway tracks, by another sewer, by a large water main, or sometimes merely by a low stretch of ground which happens to lie at such a level

that the sewer cannot be carried across it at the regular grade. Inverted siphons have often been constructed and operated successfully. It is wise, however, to take certain precautions in their design and construction, as otherwise serious trouble may be experienced with them.

First, as to material, it may be said that ordinary sewer pipe is not well suited to carry sewage under pressure, on account of the great difficulty in making absolutely tight joints, and on account of the brittle and unreliable nature of the pipe as to resistance to bursting pressures. If used under pressure, pipe sewers should be subjected to only a few feet of head, and all joints should be thoroughly encased in impervious Portland cement mortar and concrete, reinforced with imbedded steel bands. Brick masonry is still less suited to withstand bursting pressures. Ordinarily iron pipe should be used for inverted siphons.

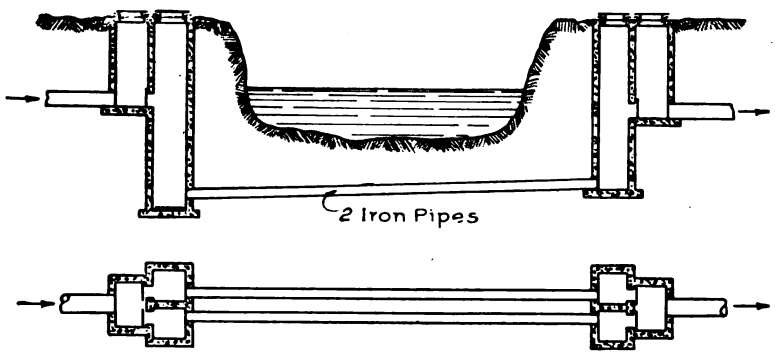


Fig. 15. Sectional Elevation and Plan of Inverted Siphon.

Second, it is especially important to insure a current in the inverted siphon sufficiently rapid to prevent deposits. If the flow is light at first, to increase afterwards, as is often the case, it is well to divide the siphon into two or more pipes with valves on each, so that the entire flow can be turned into one at first. If it is easy to add the second pipe in the future, it may often be left out at first. Thus in Fig. 38, the inverted siphon from the 18-inch outlet sewer to the septic tank is at present only an 8-inch cast-iron pipe, with provision for adding a 12-inch cast-iron pipe later.

Third, the design should be such as to permit ready access for inspection and removal of obstructions. The inverted siphon should,

if possible, be so planned that the flow of sewage can be diverted for a short time, either into one pipe, or entirely away from the siphon; and the siphon should drain to a low point from which the contents can be removed by gravity through a blow-off or by being pumped out. Where feasible, and especially where it will be very difficult (as under a stream) to dig down to the siphon in emergencies, the siphon should be made absolutely straight in grade and alignment, and a manhole placed at each end.

In Fig. 15 is shown an outline of an inverted siphon designed according to the above principles.

Where the siphon can readily be opened for repairs, as is the case with the one in Fig. 38, such expensive construction need not be resorted to. The one in Fig. 38, which carries sewage across low ground to a sewage tank about seven feet above the surface, is laid at an average depth of about six feet, and neither the grade nor the alignment is straight. It drains, however, to a low point, where a blow-off into a sewer is placed.

29. Outlets for Sewer Systems. We have heretofore discussed the house connection, and the laterals, submains, and main sewers, with their manholes, flush-tanks, and other accessories. We come next to the *outlet*, which, though not considered first here, would be one of the first things a sewerage engineer would have to consider in designing a sewer system.

Where possible, all of the sanitary sewage or combined sewage of the city should be led to one outlet, as the cost of disposing of it properly may be lightened thereby, and as the danger of injunction suits and other legal difficulties arising from damages from impurified or only partially purified sewage may be multiplied with the number of outlets. Often this will be possible by constructing comparatively short lengths of deep sewers where at first sight the topography would seem to make it impossible to secure one outlet. The size of the city, as well as the topography, will affect the number of outlets.

Storm sewage in the separate system can usually be discharged through a number of outlets into nearby natural watercourses.

Great effort should be made to secure an outlet or outlets for the sewer system low enough to drain all parts of the city by gravity. Pumping of the sewage or a material part of it, will mean a continuous expense involving an amount which would be sufficient to

pay the interest on a large initial expense to secure a gravity outlet. Besides, there is the danger of such apparatus failing at critical times.

Usually effort is made to secure, if possible, an outlet into a considerable stream or body of water, even if the sewage is to be purified.

30. Sewage Disposal. Heretofore, sewage has been disposed of, in the great majority of cases, by simply emptying it into the largest available stream or body of water near at hand. Such serious contamination of natural waters has resulted from this practice, that at the present time much more attention than formerly is being paid to sewage purification; and usually the outlet plans should be made with the expectation that some method of purification will have to be adopted in the future, if not at present.

Sewage disposal is discussed further on, at much greater length (see Arts. 110 to 124). It will only be said here that the methods at present in favor almost all involve passing the sewage through large tanks, and then through some form of filter.

SEWER MATERIALS AND CROSS-SECTIONS

31. Sewer Materials. Sewers 24 inches in diameter and under, are usually built of *vitrified sewer-pipe.* A 24-inch pipe sewer, laid to a fall of 0.2 feet in 100 feet, will carry the sanitary sewage, under average conditions, of 29,000 people; and hence it is evident that in separate systems, all the sanitary sewers will be made of pipe, except a few main and outlet sewers in large cities. Considerable percentages of storm sewer and combined sewer systems will be pipe sewers also.

Occasionally *cement sewer-pipe* is used instead of the vitrified pipe.

Sewers 30 inches and larger in diameter, are most frequently built of *brick*. Pipe is sometimes used, however, for 30-inch to 36-inch sewers.

Concrete has of late years been growing in favor, to take the place of brick in sewer construction.

Stone was formerly used to a considerable extent for sewers; but on account of its roughness, and the great cost of cut-stone masonry, stone is suited only for backing brick linings in larger sewers. Even here, concrete would now ordinarily be employed, as both cheaper and better.

Occasionally, as in the case of submerged-outlet sewers into bodies of water, or sewers across marshes on soft foundations, *wooden stave pipe* is used for sewers. These pipes are made of pieces of timber, usually about two inches by four inches in size, put together breaking joints in the field, and hooped at regular intervals with iron bands which can be screwed tight. Wood should be used only where it will be wet all the time, to prevent rotting.

Cast-iron pipe, such as is used for water mains, is often adopted for short stretches of sewer under railways or streams where great strength is essential; for inverted siphons; and in cases where absolutely water-tight joints are essential, such as submerged lines in lakes, harbors, and stream crossings, or where there is much ground water.

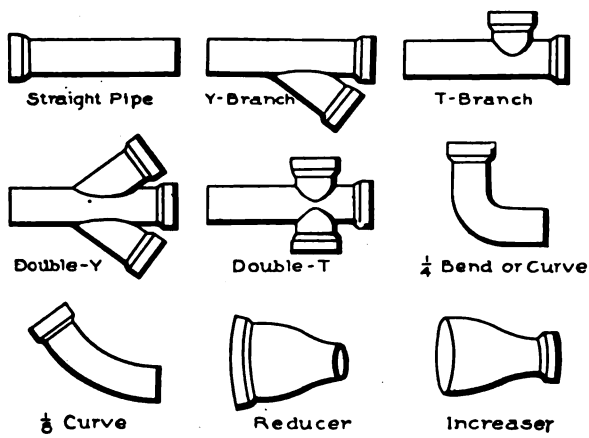


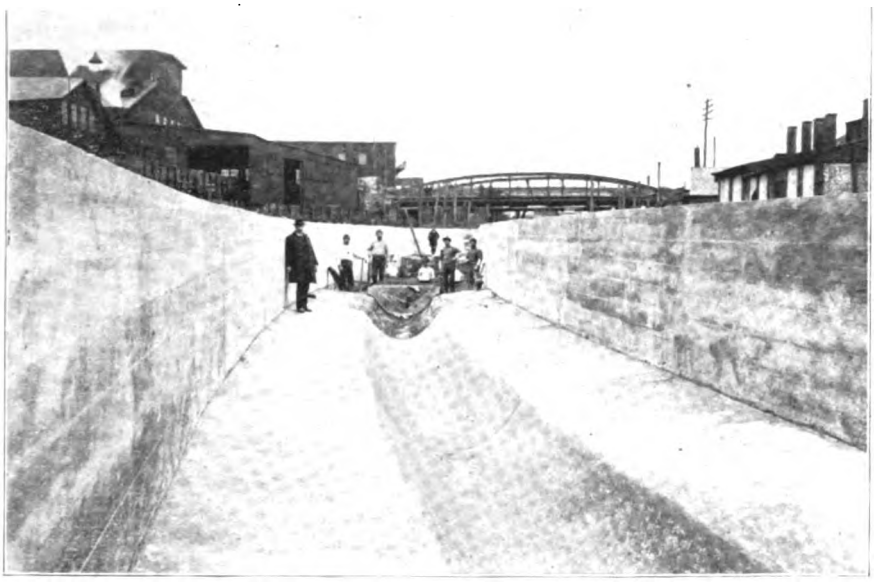
Fig. 16. Vitrified Sewer-Pipe and Specials.

32. Vitrified Sewer-Pipe. Vitrified sewer-pipe has many excellent qualities for sewer use. It is hard, impervious, smooth, strong, does not decay or disintegrate, and is not affected by chemicals. It has few joints as compared with brickwork, and these joints are of convenient shape to make practically water-tight. Vitrified sewer-pipe is readily handled and laid in sewer construction. The materials of which it is made are widely distributed, and hence the cost of the pipe is reasonable.

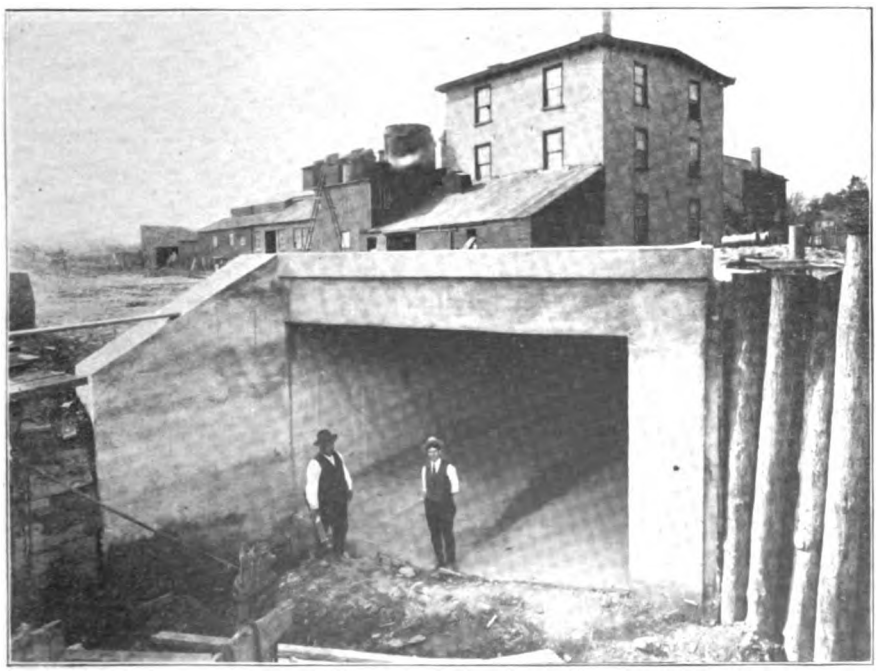
In Fig. 16 are shown the general forms of the straight pipe and also of the special fittings (*sewer-pipe specials*) most commonly used in sewer construction.

In Table I (page 35) are given standard dimensions for straight sewer-pipe.

Vitrified sewer-pipe is made from shale clays, in very much the same way as brick and other clay products. The temperature at



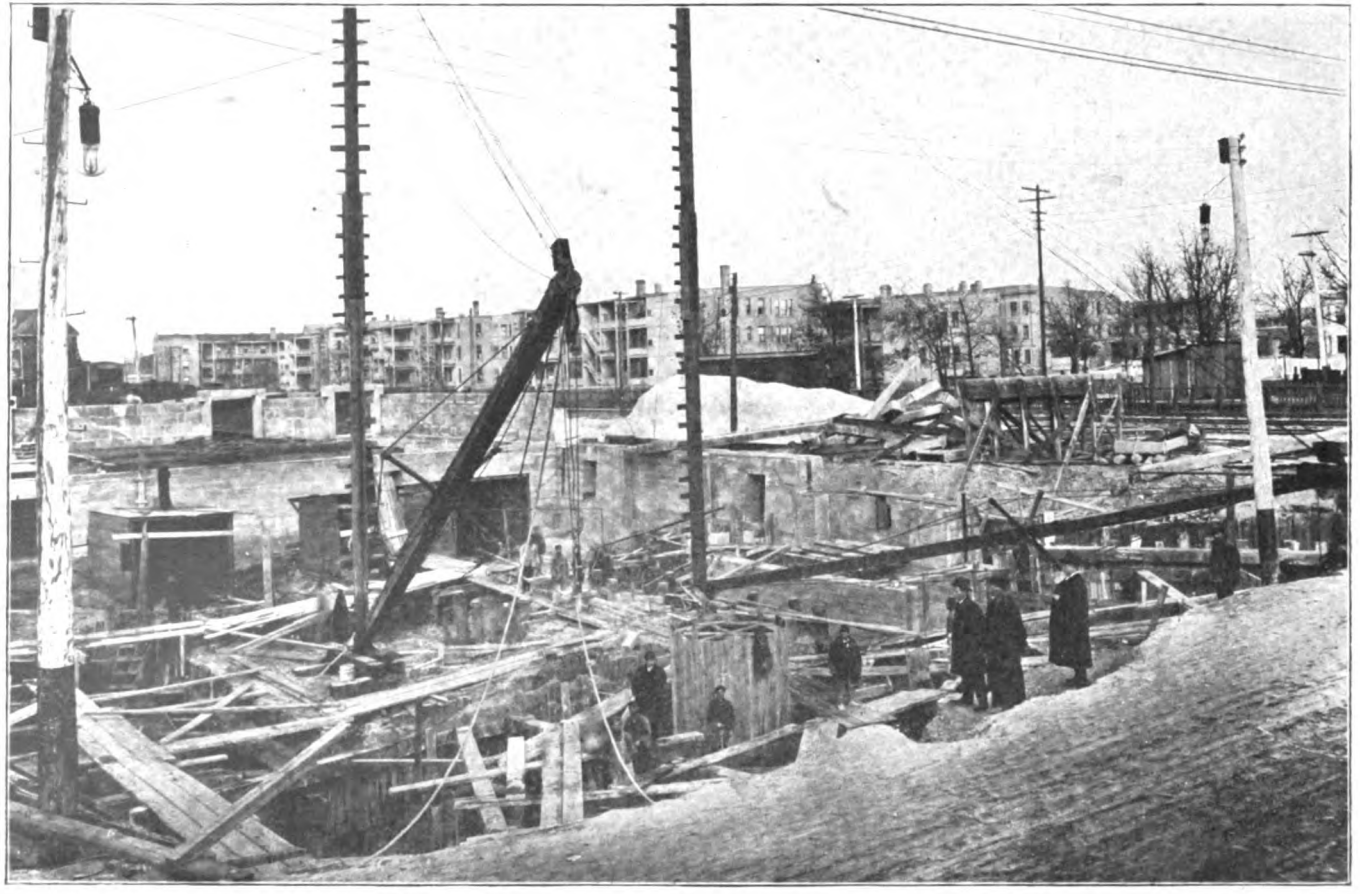
Large Concrete Sewer in Aramingo Canal.



Wakeling Street Concrete Sewer, 16 ft. by 10 ft. 6 in.

TWO VIEWS OF SEWERS IN THE CITY OF PHILADELPHIA, PA.

Courtesy of Geo. S. Webster, Chief Engineer, Bureau of Surveys, Dept. of Public Works.



LAWRENCE AVENUE PUMPING STATION, SYSTEM OF INTERCEPTING SEWERS, CHICAGO, ILL., UNDER CONSTRUCTION

The intercepting sewers run parallel to the shore of Lake Michigan, preventing egress of sewage to the lake. At certain points the sewage is pumped to higher levels, and allowed to flow by gravity westward into the new outlet afforded by the Drainage Canal.

which it is burned in the kilns must be very high, as in the case of paving brick, so as to produce an "incipient vitrification," a softening and running together of the particles of clay, which gives, on cooling, a very hard, impervious, and strong structure. Smoothness of interior and exterior surfaces is secured by the use of salt during the process of burning, so as to produce a "salt-glazed," glassy skin.

TABLE I

Standard Dimensions for Sewer Pipe

STANDARD				DOUBLE STRENGTH OR EXTRA THICK			
Inside Diam. Inches	Thickness of Shell. Inches	Depth of Socket. Inches	Weight per Ft. Lbs.	Inside Diam. Inches	Thickness of Shell. Inches	Depth of Socket. Inches	Weight per Ft. Lbs.
8	¾	2½	22	8	⅞	2½	25
9	¾	2½	27	9	⅞	2½	30
10	⅞	2½	30	10	1	2½	34
12	1	2½	41	12	1⅛	3	50
15	1⅛	3	60	15	1¼	3	70
18	1¼	3	80	18	1½	3	100
20	1⅜	3	95	20	1⅝	3	120
21	1⅜	4	105	21	1¾	4	140
24	1⅝	4	135	24	2	4	180
27	2	4	215	27	2¼	4	240
30	2¼	4	270	30	2½	4	300
33	2⅜	4½	320	33	2⅝	4½	340
36	2½	5	365	36	2¾	5	390

The bells are made large enough to allow an annular space for cement, ranging from ⅜ inch thick for 8-inch pipe to ¾ inch for 36-inch pipe.

Smaller sizes of pipe, down to 3 inches in diameter, are made.

Double-strength pipe is used only in cases requiring unusual strength.

Vitrified sewer-pipe must be carefully inspected, piece by piece, just before being used in the sewer, all poor material being rejected. Some of the points to be noted in making the inspection are as follows:

(1) The pipe should be straight, and true in shape.

(2) The pipe must have a hard-burned, strong internal structure showing incipient vitrification. Small pieces may be chipped out of occasional lengths to test this; and the color will also be a guide after the inspector has become thoroughly familiar with the make of pipe being used.

(3) The hub and socket ends of adjacent pipes should fit together well, leaving at least the spaces for cement given under Table I.

(4) There must not be on the lower half of the interior of the sewer any lumps, blisters, or excrescences. A few may be allowed,

if not too large, if the pipe can be turned so as to bring them to the upper half.

(5) There must be no cracks extending into the body of the pipe, or of such nature as to weaken it materially. On tapping the pipe with a light hammer, if it does not give a clear ring, the presence of invisible cracks may be suspected.

(6) There must be no broken pieces of material size, from either the hub or the socket ends, nor any at all which cannot be turned to the upper half.

Nothing of human construction can be perfect, and sewer pipes are no exception to the rule. Hence the pipe inspector must have good judgment and considerable experience to draw the line properly between important and unimportant defects. In clause 25, Art. 93, of the sewer specifications given hereinafter, some definite rules are laid down to govern inspectors in this particular.

Vitrified pipe can be secured in 2, 2½, and 3-foot lengths. The longer the lengths, the fewer the joints, which is a material advantage.

33. Joints in Pipe Sewers. The joints are the weakest points in pipe sewers, and should be made with the utmost pains to secure as nearly as practicable an absolutely water-tight job. In Fig. 17, the upper joint shown illustrates the form commonly employed.

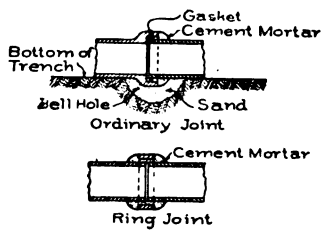


Fig. 17. Joints in Pipe Sewers.

In the bottom of the trench, which should be rounded to fit the under part of the sewer pipe, *bell-holes* are dug for all bells, to permit the joint on the under side of the pipe to be made properly, and to give the pipe a bearing on its full length instead of merely on the bells. Before the spigot end of the pipe to be laid is *entered* into the bell of the last pipe laid, it should be wrapped with a *gasket* of hemp, oakum, or jute, as shown in Fig. 17, so that the inverts of the two pipes will match in a smooth line when the pipe is entered, and so as to prevent the soft cement mortar from being forced up through the joint to project into the pipe. The gasket also assists in making the joint water-tight, especially if there is water in the trench. Disastrous results have often followed the omission of the gasket, which should always be used.

After the pipe is entered and brought exactly to grade, Portland cement mortar, mixed about 1 to 1 or 1 to 2 with sand, should be *calked* into the joint, *to fill it absolutely full*, and should be beveled off on the outside, as shown in the figure. Special care should be taken on the under side of the pipe. *Immediately* after placing the cement, the bell-hole should be packed *full* of sand, so as to support the cement on the under side of the pipe till it has set. It is best to keep the cementing back two or three lengths of pipe from the pipe laying, to avoid danger of the cement being broken in placing the next pipe.

Without the most careful watching of every joint during construction, the workmen are sure to slight the joints. An inspector should be kept constantly on the work.

In the lower part of Fig. 17 is shown the *ring joint*, formerly preferred by some engineers, but now very seldom used. It is more costly than the ordinary form.

Various joints have been invented and used to a limited extent, which include simple beveling of the ends of the pipe without using bells, the use of grooves at one end with corresponding projections at the other end, etc. Sometimes the exterior of the spigot end and the interior of the bells are grooved and made rough in the ordinary form of joint. This is an advantage in holding the cement, and in securing a water-tight job.

34. Cement Sewer-Pipe. Ever since the early use of pipe sewers in the latter half of the nineteenth century, cement pipe has been used to some extent for sewers; and recently there seems to be a revival and extension of its use. Experience has shown that cement is a very suitable material for making sewer pipe, and that cement pipes, when well made, of first-class materials, give excellent satisfaction for sewers, and are durable and not disintegrated by the sewage.

The manufacture of good cement sewer-pipe, however, cannot be successfully carried on by men who do not have the necessary skill, which is to be gained only by experience in this particular work; and even skilled manufacturers will not be successful unless both the cement and the sand used are of first-class quality, nor unless plenty of cement is used. Much poor cement pipe has been made, because these almost self-evident facts have not been understood; and in this way cement sewer-pipe has gained a bad reputation in many localities.

In general it may be said that the sand should be clean, sharp, and coarse, and that it should contain a considerable proportion of fine pebbles, smaller than a cherry-pit. Only the best Portland cement should be used, and the mortar should not be weaker than 1 to 3. The mixing must be very thorough, as also the tamping into the moulds.

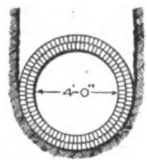


Fig. 18. Circular Brick Sewer, Ingersoll Run, Des Moines, Iowa.

Two general kinds of cement sewer-pipe are made. In one, just coming into use, the pipes are made continuously in the ditch. A form of moulds is used to give the correct shape and size, which can be forced ahead as the work progresses; and there are no joints. It is too soon yet to tell how successful this plan may be.

In the more common form of cement sewer-pipe, the pipes are made in a factory, in pieces of the same length as vitrified pipe. Usually, comparatively little water is used in mixing, in order to permit immediate removal of the pipe from the moulds. While such pipe are *curing* (setting), the omitted water must be supplied by frequently wetting them, or the process of setting and hardening cannot go on properly. Many cement sewer-pipes of this kind are spoiled in the curing.

Fig. 19. Egg-Shaped Brick Combined Sewer.

Cement pipe are now made with bells for the joints, the same as vitrified pipe. The manufacture of specials, such as the Y-junctions required in such numbers for house connections, is still in unsatisfactory condition.

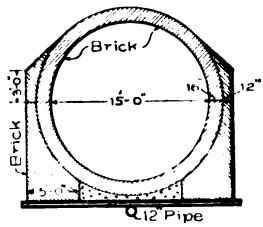


Fig. 20. Circular Brick Sewer with Subdrain, 64th Street, Brooklyn, N. Y.

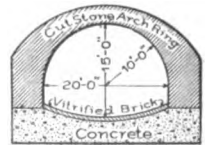
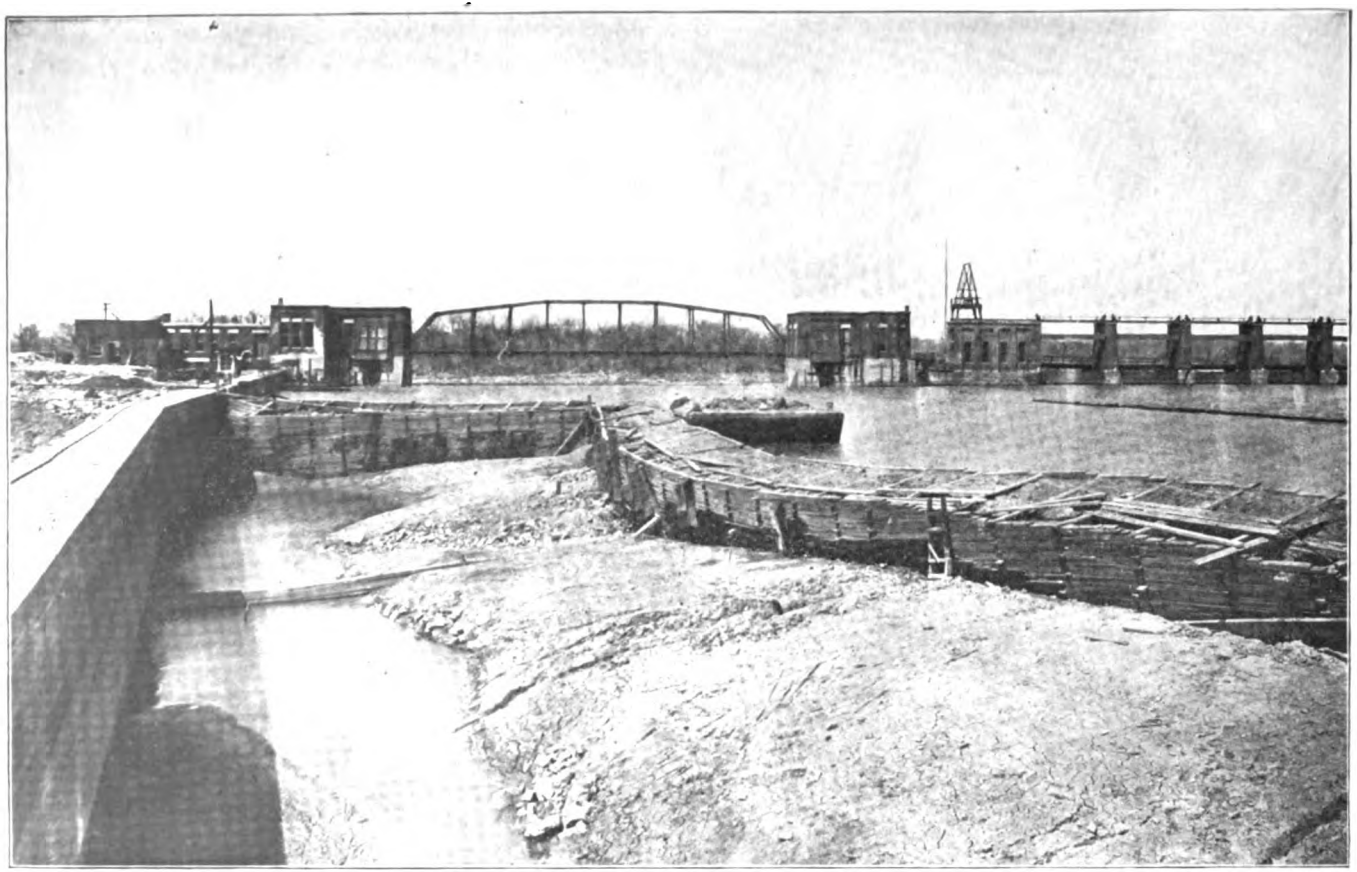


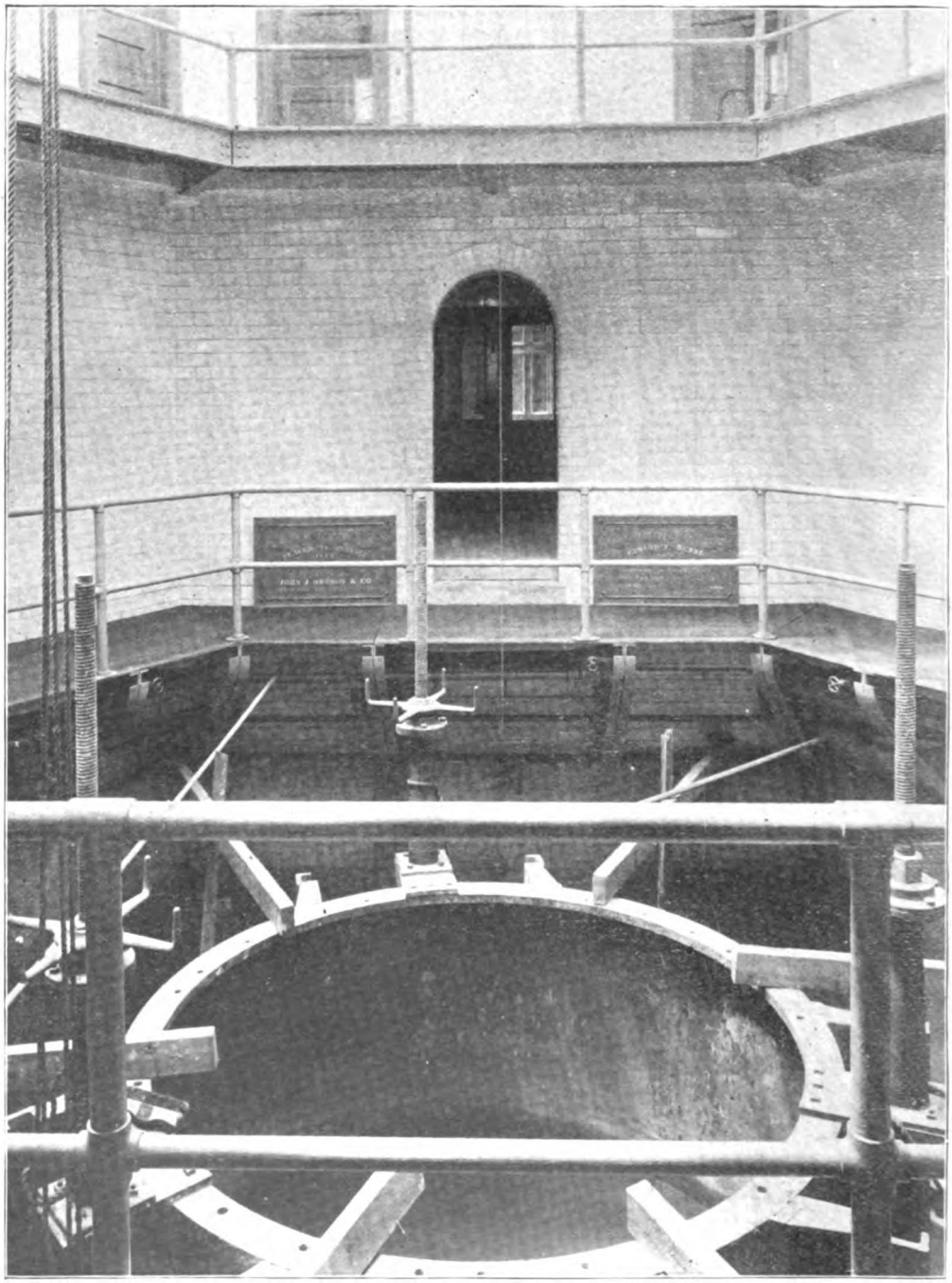
Fig. 21. Section of a Large Sewer in St. Louis, Mo.

The body of a cement sewer-pipe is of much weaker material than that of which vitrified pipe are made; and the thickness of cement pipe should be much greater than the thickness given in Table I for vitrified pipe.



PART OF DAM CONSTRUCTION ON CHICAGO DRAINAGE CANAL AT LOCKPORT, ILL.

The temporary dam of stone, clay, and concrete here shown diverts water from the "Butterfly" dam and the new channel, to the "Bear Trap" dam and the Desplaines River.



INTERIOR OF LAKEVIEW CRIB, CHICAGO WATERWORKS SYSTEM
Showing intake shaft.

35. Typical Cross-Sections of Large Sewers. In Figs. 18 to 25, inclusive, are shown some typical designs for sewers too large to be constructed of sewer pipe.

In Fig. 18, the common circular form is shown. This form is more economical to construct than any other when good foundations

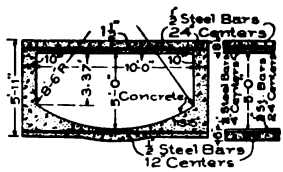


Fig. 22. Ingersoll Run Sewer with Low Headroom, Des Moines, Iowa.

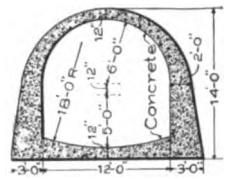


Fig. 23 Dry-Run Sewer, Waterloo, Iowa.

can be had, for the circle gives a larger area and velocity of flow when full than any other shape having the same circumference.

In the case of combined sewers, however, the dry-weather flow of sewage is so very small, in comparison with the size of the sewer, that it makes only a shallow, trickling stream of little velocity, and the sewer will not be self-cleansing. For such sewers, this difficulty can be overcome by the use of the egg-shape of sewer, shown in Fig. 19. This shape has a circular invert having a radius only half that of the top; and the depth and velocity of the dry-weather flow will be the same as in a circular sewer of this smaller radius, while at the same time the capacity in time of flood is equivalent to a much larger circle.

In Fig. 20, a favorite type of design for very large circular sewers

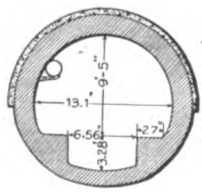


Fig. 24. Old Type of Main Sewers, Paris, France.

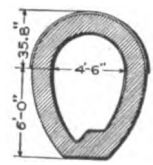


Fig. 25. New Type of Sewers, Paris, France.

is shown. For such large sewers, the upper half constitutes an arch, which exerts heavy pressures or thrusts horizontally outward against the sides of the sewer at the height of the center. To withstand these thrusts, the masses of masonry backing shown in the figure are added. This backing may be of brick, rubble-stone, or concrete masonry.

In the large sewers, too, it usually is not practicable to round the bottom of the trench to fit the circular shape, as is done for smaller sewers; and hence the flat foundation, also shown in the figure, is adopted. In soft materials, it often becomes necessary to drive piles to carry the weight of sewers.

In Fig. 21 is shown the favorite design for large sewers. For reasons given in discussing Fig. 20, the foundation is necessarily made flat; and with this shape of foundation, Fig. 21 will give a larger area and capacity for the same amount of material than Fig. 20, other conditions being the same. Also, Fig. 21 requires less headroom than Fig. 20 for the same capacity—which is often of great importance in the case of these large sewers. The invert of Fig. 21 is not so well suited to prevent deposits as that of Fig. 20; but in the case of these large sewers, there is usually a large flow even in dry weather, so that this point may be of little importance.

In Fig. 23 we have an example of the use of concrete for a large sewer of the general type shown in Fig. 21, and just discussed.

In Fig. 22 we have an extreme case of low headroom, secured by making the top an absolutely flat slab of concrete, reinforced with steel. In this case the bottom of the sewer was necessarily located at a very shallow depth below the street, while the required size of sewer was large.

Finally, in Figs. 24 and 25, are shown two typical cross-sections of the famous sewers of Paris. The large main shown in Fig. 24 acts not only as a sewer, but also as a subway for the water mains and for other purposes. The entire ordinary flow of sewage is confined within the *cunette*, or comparatively small channel shown in the bottom. The ledge on each side serves for the passage of workmen and of cleaning carts, flushing devices, etc. The section shown in Fig. 25 is a later type, and is more nearly self-cleansing. The dirt in the streets is washed into these sewers by the use of hose, and special conveniences for cleaning it out of the sewers are needed.

36. Junction-Chambers for Large Sewers. Where two or more large sewers join, special difficulties present themselves, in providing supports for the partial arches whose supports are cut away in making the junction. It is usually necessary, when the sewers are large, to build a masonry chamber enclosing the entire junction, and with a self-supporting roof spanning all the sewers.

Various designs for such junction-chambers are used, but the most common type is illustrated in Fig. 26. Here a *bell-mouth arch* is used to span the opening, the case being the junction of three of the Chicago intercepting sewers (see Fig. 5). Sometimes *flat roofs* are used, supported by steel beams or made of reinforced concrete.

The bottoms of such junctions are the *mathematical intersections*, executed in masonry, of the lower halves of the sewer channels; and for sewers not too large, the upper halves may sometimes be built in a similar way, or with *vault ribs*, as in the roofs of old cathedrals.

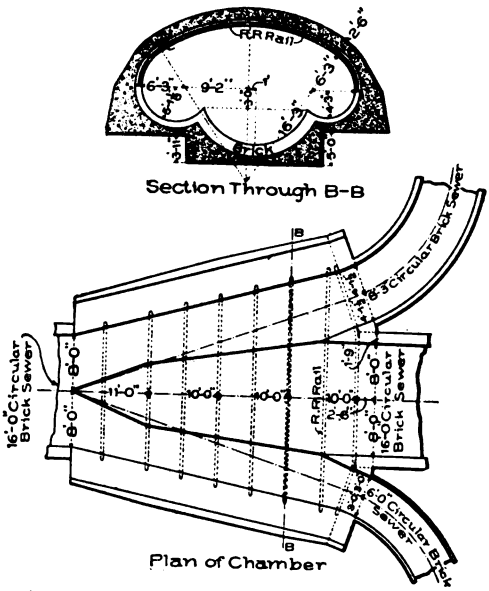


Fig. 26. Junction of Brick Sewers, Lawrence and Sheridan Avenues, Chicago, Ill.

37. Brick Sewers. It has already been stated that brick is the favorite material for sewers too large to be made of pipe, the dividing line usually being drawn at 30 inches to 36 inches diameter. Brick present many advantages for sewer work, including their moderate cost, their durability, and their small size and regular shape, which enable them to be readily handled and used in building sewers of any desired cross-section, with comparatively smooth and true interior surfaces.

Sewer brick, as those suitable for sewer construction are commonly called, should be harder burned than ordinary building brick, to enable them to stand the wear from the flow of sewage, and to insure against disintegration. They need not, however, be as hard burned as No. 1 paving brick, and hence constitute an intermediate grade between building brick and pavers. Sewer brick should be uniform in size, and of regular, true shape, so as to permit of being laid with thin joints, to form smooth, true surfaces. They should be carefully inspected on the work just before being used, and all defective brick

thrown out. The common size for sewer brick approximates 8½ by 4 by 2¼ inches.

In the sewer, the brick are laid in rings, as shown in Figs. 18 and 19, with the 4-inch dimension radial and the 8½-inch dimension lengthwise of the sewer. Care should be taken to *break joints* in each ring. The brick should be laid in Portland cement mortar, made of at least 1 part of cement to 3 parts of clean, sharp sand of medium-sized grains. Pebbles should be screened out of the sand so as to permit thin joints. All joints should be filled *full* of mortar, the brick being laid with *shove joints*, to make a practically water-tight job. The outside ring of the invert should be laid against a layer of 1 to 2 Portland cement mortar; and the outside of the arch (or upper half of the sewer) should be plastered with the same mortar, to keep out ground water. Similarly, to prevent leakage of sewage, the entire interior surface of the sewer should be plastered with the same mortar, or else thoroughly washed with at least two coats of liquid cement, after the joints have been carefully pointed and smoothed. Even with the utmost care, it will be found impossible to secure absolute water-tightness; and the difficulties will be especially great when ground water and soft materials are encountered in the trench.

Up to 6 or 7 feet diameter, two rings of brick are usually sufficient. In fact, for the smaller sizes of brick sewers, one ring would be amply strong with firm foundations; but it is difficult to make the sewer sufficiently tight when only one ring is used, because all joints extend entirely through. Sometimes an exterior layer of concrete may be used to meet this objection, at least for the lower half of the sewer; or an outside ring of brick may be used for the invert only. Sewers larger than 6 or 7 feet in diameter usually require three rings of brick; and more are needed for very large sewers, for which the number required must be calculated for each particular case to suit the special conditions.

38. Concrete Sewers. Of late years, concrete has frequently been employed in preference to other kinds of masonry for many purposes, of which sewer construction is one. Its advantages for sewers are many. The following may be mentioned:

First, and foremost, the cost is usually less than the cost of brick masonry.

Second, the concrete exactly fits the irregularities of the excavation, giving better foundations.

Third, sewers built of concrete constitute a solid structure without joints, and hence are less liable to uneven settlement.

Fourth, there are no joints, as in brickwork, to be made watertight, though, on the other hand, it is not easy to make the body of the concrete entirely impervious to seepage.

Fifth, the concrete can be readily moulded to any desired shape of sewer.

Sixth, the concrete can be made by comparatively unskilled workmen, if skilled foremen are employed.

Concrete may be used for foundations, as shown in Figs. 20 and 21; for the backing of brick sewer rings; and in various other combinations with brick; or it may be used for the entire sewer, as in Figs. 22 and 23.

Reinforced concrete, or concrete reinforced with steel rods, to prevent cracks from tension stresses, has opened up of late years entirely new possibilities in sewer construction, of which Fig. 22 is an example.

It has been reported that the concrete invert of the large St. Louis sewer shown in Fig. 21 has shown surface pitting and disintegration from the effects of the sewage. This is a trouble which does not appear to have been experienced elsewhere, and hence is presumably uncommon, and would seem due most probably to poor materials or poor workmanship. Danger from this source could be prevented by lining the concrete sewer with one ring of vitrified paving brick.

FORMULÆ AND DIAGRAMS FOR COMPUTING FLOW IN SEWERS

39. Formulæ for Computing Flow in Sewers. It has already been stated that more than 99.8 per cent of even sanitary sewage is simply ordinary water which has been added to the foul wastes to assist in removing them. Hence the mathematical formulæ for the flow of sewage are the same as those for the flow of water. They may be studied in detail in the instruction paper on Hydraulics.

Two general hydraulic formulæ have commonly been employed in sewer computations, as follows:

(1) *Weisbach's Formula.* The older computations were generally based on Weisbach's formula, which is as follows:

$$v = \frac{\sqrt{2gh}}{\sqrt{1 + e + c\frac{l}{d}}}.$$

In the above formula,

v = Average velocity of flow, in feet per second.
g = Acceleration due to gravity = 32.2 ft. per second.
h = Fall of sewer, in feet.
e = Coefficient of entrance = 0.505.
c = Coefficient of friction in pipe = $0.0144 + \frac{0.0169}{\sqrt{v}}$.
l = Length of pipe, in feet.
d = Diameter of pipe, in feet.

Weisbach's formula has been much used for sewer computations, for the reason that Mr. Baldwin Latham, in the first treatise on Sanitary Engineering worthy the name (1873), published extensive tables of flow, calculated from this formula, which made sewer computations very simple. Hence it was easier for later engineers simply to make use of these tables than to compute new ones of their own.

(2) *Kutter's Formula.* In later hydraulic computations, it has generally been considered that Kutter's formula gives the most reliable results. It is as follows:

$$v = c\sqrt{RS} = \left\{ \frac{41.66 + \frac{1.811}{n} + \frac{.00281}{s}}{1 + \left(41.66 + \frac{.00281}{s}\right)\frac{n}{R}} \right\} \sqrt{RS}.$$

In this formula,

v = Average velocity of flow, in feet per second.

R = Mean hydraulic radius in feet = Area of cross-section of stream in square feet, *divided by* wetted perimeter, in feet, of length of portion of circumference of channel wet by the stream. (NOTE.—For circular pipe sewers, $R = \frac{1}{4}$ of the diameter when the pipe is flowing either full or half-full.)

S = Slope of the sewer = $\frac{\text{Fall}}{\text{Length}}$.

n = Coefficient of roughness, varying with the roughness of the channel.

For pipe sewers it is common to assume that $n = 0.013$; and for brick sewers, that $n = 0.015$. For cement pipe sewers, the roughness might be considered intermediate between these values of n; but $n = 0.013$ is generally used for them as well as for clay pipe. New and perfectly clean channels

would not be so rough as indicated by these numbers; but the growths and deposits which may accumulate in sewers render it wise to adopt the above values for n.

Both the above sewer formulæ give merely the average velocities (v) of flow. *To obtain the discharge in cubic feet per second, we must multiply "v" by the area in square feet of the cross-section of the stream of sewage.*

Kutter's formula gives less capacities for pipe sewers than Weisbach's for the small sizes, up to about 18 inches' diameter. It will be on the safe side to adopt Kutter's formula; and this is now very generally done, though actual gaugings of small pipe sewers either new or in very good condition, may often show greater velocities and capacities than the formula would indicate, when the values of n above given are adopted.

In this paper, Kutter's formula will be adopted as the basis of all calculations of the flow of sewers.

40. Diagram of Discharges and Velocities of Circular Pipe Sewers Flowing Full. Direct numerical computations of flow in sewers from the formulæ given above, would be very laborious and tedious. The work may be very greatly simplified by the use of tables or diagrams. Diagrams are more convenient than tables, and are adopted for this paper. With their aid, computations of flow in sewers are very easy and short.

Fig. 27 is such a diagram, giving the capacities and velocities of circular *vitrified* pipe sewers flowing full. *Cement* pipe sewers would probably have discharges and velocities somewhat less than those shown in this figure.

TO USE THE DIAGRAM

(*A*) *When the diameter of the pipe and the grade are given, to find the discharge and the velocity.*

(1) Look along the bottom horizontal line till the grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the point where the vertical line through the given grade intersects the inclined line marked with the given diameter of sewer. (3) Trace horizontally through this point, interpolating by the eye, if necessary, between the horizontal lines on the diagram; and read the discharge of the pipe running full, on the left side of the diagram in cubic feet per second, or on the right side of the diagram in gallons per 24 hours. (4) If the velocity is desired, it can be determined by noting where the point (found in 2, above) of intersection of the given grade and diameter lines falls with reference to the inclined lines marked with the different velocities, estimating by the eye the decimals of a foot per second.

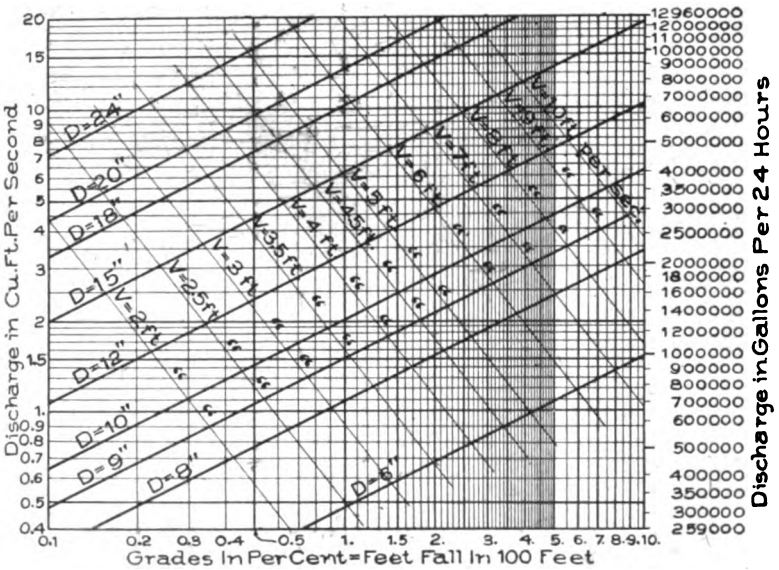


Fig. 27. Discharges and Velocities of Circular Vitrified Pipe Sewers Flowing Full. By Kutter's Formula ($n=0.013$).

(*B*) *When the grade and the required discharge are given, to find the necessary diameter of pipe, and the velocity.*

(1) Look along the bottom horizontal line till the given grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the intersection of the vertical line through this grade with the horizontal line through the given discharge, finding the discharge on the left of the diagram if it is given in cubic feet per second, or on the right if it is given in gallons per 24 hours. (3) Note between which two diameter lines this point of intersection falls, and take the diameter line nearest as that required. (4) Also note the position of the point of intersection with reference to the velocity lines, and so estimate the velocity, interpolating by the eye between the inclined velocity lines.

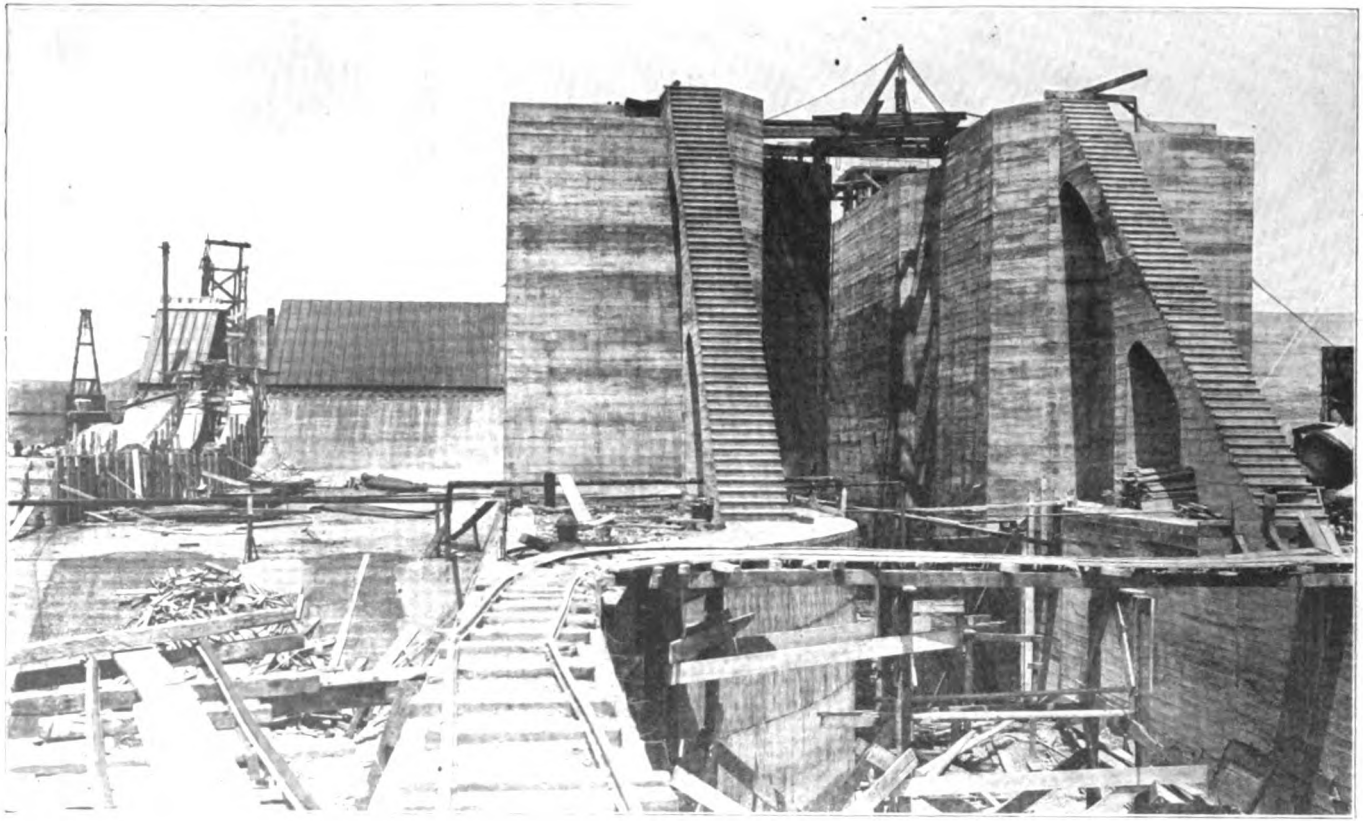
(*C*) *When the velocity and diameter are given, to find the grade and discharge.*

(1) Find the intersection of the given diameter line with the given velocity line, interpolating by the eye, if necessary. (2) Then vertically downward to the bottom of the diagram from this point of intersection, read the required grade; and horizontally to the left side or to the right side of the diagram, read the discharge, interpolating by the eye in each case, if necessary.

All other cases may be solved by similar obvious methods.

EXAMPLES

Example 1. What will be the discharge and velocity of a 15-inch pipe sewer laid to a 0.2 per cent grade?



ENTRANCE TO LOCK ON CHICAGO DRAINAGE CANAL, LOCKPORT, ILL.

Lift, 40 feet.

Courtesy of R. I. Randolph.

Solution. See *A*, above. From the intersection of the vertical 0.2 per cent grade line with the inclined 15-inch diameter line, we read horizontally to the left the discharge of 2.8 cu. ft. per second, or to the right, of 1,850,000 gallons per 24 hours. We further note that the point of intersection of the 0.2 per cent grade line with the 15-inch diameter line falls between the 2.0 and the 2.5 ft. per second velocity lines, and by the eye we estimate the velocity to be 2.3 ft. per second.

Example 2. See *B*, above. What size of pipe sewer laid at a grade of 0.5 per cent will be required to carry an average flow of 200,000 gallons of sewage per day, the maximum rate of discharge being three times the average? (NOTE.—Hence use 600,000 gallons discharge in solving the example.) Also, what will be the velocity?

Answer. Required diameter of sewer, 9 inches; velocity of flow, about 2.3 ft. per second.

Example 3. See *C*, above. If the minimum allowable velocity of flow is 2 ft. per second when a sewer flows full, what minimum grade will be required to produce this velocity in a 12-inch sewer?

Answer. 0.23 per cent minimum grade.

Example 4. If an outlet sewer serves 20,000 people, each person contributes 100 gallons per day, and the maximum rate of flow is 3 times the average, what size of sewer will be required, if its grade is 0.25 per cent?

Answer. 24 inches diameter.

Example 5. If an 8-inch pipe sewer is laid at a 0.45 per cent grade, what will be the discharge and the velocity when it flows full?

Answer. 480,000 gallons per day; 2.1 ft. per second.

Example 6. A storm pipe sewer drains 10 acres, and should be able to carry 1.5 cu. ft. per second per acre. Its grade is 0.5 per cent. What diameter will be required?

Answer. 24 inches diameter.

41. Diagram of Discharges and Velocities of Circular Brick and Concrete Sewers Flowing Full. Fig. 28 is the diagram for circular brick and concrete sewers, corresponding to Fig. 27 for pipe sewers, and is used in the same way.

TO USE THE DIAGRAM

(*A*) *When the diameter of the pipe and the grade are given, to find the discharge and the velocity.*

(1) Look along the bottom horizontal line till the grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the point where the vertical line through the given grade intersects the inclined line marked with the given diameter of sewer. (3) Trace hori-

zontally through this point, interpolating by the eye, if necessary, between the horizontal lines on the diagram; and read the discharge of the pipe runn ng full, on the left side of the diagram in cubic feet per second, or on the right side of the diagram in gallons per 24 hours. (4) If the velocity is desired,

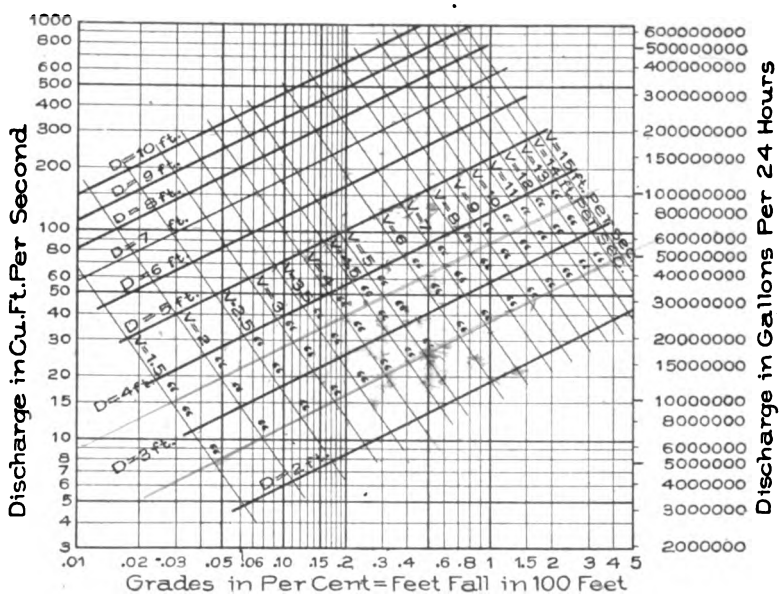


Fig. 28. Discharges and Velocities of Circular Brick and Concrete Sewers Flowing Full. By Kutter's Formula (n=0.015).

it can be determined by noting where the point (found in 2, above) of intersection of the given grade and diameter lines falls with reference to the inclined lines marked with the different velocities, estimating by the eye the decimals of a foot per second.

(*B*) *When the grade and the required discharge are given, to find the necessary diameter of pipe, and the velocity.*

(1) Look along the bottom horizontal line till the given grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the intersection of the vertical line through this grade with the horizontal line through the given discharge, finding the discharge on the left of the diagram if it is given in cubic feet per second, or on the right if it is given in gallons per 24 hours. (3) Note between which two diameter lines this point of intersection falls, and take the diameter line nearest as that required. (4) Also note the position of the point of intersection with reference to the velocity lines, and so estimate the velocity, interpolating by the eye between the inclined velocity lines.

(*C*) *When the velocity and diameter are given, to find the grade and discharge.*

(1) Find the intersection of the given diameter line with the given velocity line, interpolating by the eye, if necessary. (2) Then vertically

downward to the bottom of the diagram from this point of intersection, read the required grade; and horizontally to the left side or to the right side of the diagram, read the discharge, interpolating by the eye in each case, if necessary.

All other cases may be solved by similar obvious methods.

EXAMPLES

Example 7. What size of circular brick or concrete sewer laid to a 0.2 per cent grade will be required to carry a storm sewage flow of $\frac{3}{4}$ cu. ft. per second per acre from one square mile of drainage area, and what will be the velocity?

Solution. See *B*, above. 1 square mile = 640 acres. The capacity required is $640 \times \frac{3}{4} = 480$ cu. ft. per second, which we find on the left of Fig. 28 just below the 500 cu. ft. per second horizontal line, interpolating by eye. We next find the 0.2 per cent grade line at the bottom of the diagram, and locate the point of intersection of this vertical 0.2 per cent grade line with the horizontal 480 cu. ft. per second line already found above. This point of intersection comes nearly on the 9 feet inclined diameter line, and between the seven and eight feet per second inclined velocity lines.

Answer. Diameter of sewer required, 9 feet. Velocity = 7.6 ft. per second.

Example 8. What will be the minimum grade for a 60-inch brick or concrete sewer, if the minimum velocity allowed when flowing full is 3 ft. per second?

Answer. See *C*, above. 0.067 per cent grade.

Example 9. How large a population, contributing 75 gallons per capita per day of sanitary sewage, on the average (the maximum flow being 3 times the average), can be served by a 48-inch circular brick sewer, laid to a 0.06 per cent grade; and what will be the velocity of flow? (NOTE: Find the capacity as in *A*, above; and then divide by 3 times the average per capita amount per day.)

Answer. 89,000 population. 2.4 ft. per second.

Example 10. What will be the grade required to force a flow of 500 cu. ft. per second through a 96-inch circular brick sewer?

Answer. 0.38 per cent grade.

42. Diagram of Discharges and Velocities of Egg-Shaped Brick and Concrete Sewers Flowing Full. Fig. 29 is the diagram for egg-shaped brick sewers, corresponding to Fig. 27 for circular pipe sewers, and to Fig. 28 for circular brick and concrete sewers.

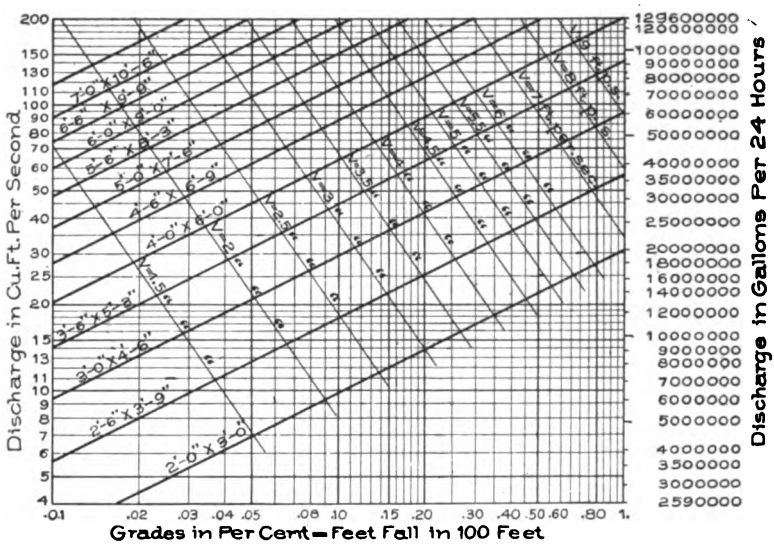


Fig. 29. Discharges and Velocities of Egg-Shaped Brick and Concrete Sewers Flowing Full. By Kutter's Formula (n=0.015).

TO USE THE DIAGRAM

(*A*) *When the diameter of the pipe and the grade are given, to find the discharge and the velocity.*

(1) Look along the bottom horizontal line till the grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the point where the vertical line through the given grade intersects the inclined line marked with the given diameter of sewer. (3) Trace horizontally through this point, interpolating by the eye, if necessary, between the horizontal lines on the diagram; and read the discharge of the pipe running full, on the left side of the diagram in cubic feet per second, or on the right side of the diagram in gallons per 24 hours. (4) If the velocity is desired, it can be determined by noting where the point (found in 2, above) of intersection of the given grade and diameter lines falls with reference to the inclined lines marked with the different velocities, estimating by the eye the decimals of a foot per second.

(*B*) *When the grade and the required discharge are given, to find the necessary diameter of pipe, and the velocity.*

(1) Look along the bottom horizontal line till the given grade is found, interpolating by the eye, if necessary, between the grades marked on the diagram. (2) Find the intersection of the vertical line through this grade with the horizontal line through the given discharge, finding the discharge on the left of the diagram if it is given in cubic feet per second, or on the right if it is given in gallons per 24 hours. (3) Note between which two diameter lines this point of intersection falls, and take the diameter line nearest as that required. (4) Also note the position of the point of intersection with reference to the velocity lines, and so estimate the velocity, interpolating by the eye between the inclined velocity lines.

(*C*) *When the velocity and diameter are given, to find the grade and discharge.*

(1) Find the intersection of the given diameter line with the given velocity line, interpolating by the eye, if necessary. (2) Then vertically downward to the bottom of the diagram from this point of intersection, read the required grade; and horizontally to the left side or to the right side of the diagram, read the discharge, interpolating by the eye in each case, if necessary.

All other cases may be solved by similar obvious methods.

EXAMPLES

Example 11. What will be the discharge and velocity of flow of a 4 by 6-feet egg-shaped brick or concrete sewer flowing full and laid to a 0.4 per cent grade?

Solution. *See A*, above. Find the 0.4 per cent grade line at the bottom of Fig. 29, and locate the point of intersection of the vertical line through this point with the inclined 4 by 6 dimension line. Then tracing horizontally to the left, we estimate by the eye 128 cu. ft. per second for the discharge. We also note that the point of intersection of the vertical 0.4 per cent grade line with the inclined 4 by 6 dimension line found above, is practically on the inclined 7 ft. per second velocity line.

Answer. Discharge, 128 cu. ft. per second. Velocity, 7 ft. per second.

Example 12. What will be the size of egg-shaped brick or concrete sewer required to carry a storm flow of ½ cu. ft. per second per acre from a drainage area of ½ square mile (= 320 acres), the grade being 0.3 per cent?

Answer. See *B*, above. 4 ft. 6 in. by 6 ft. 9 in.

Example 13. A 6-foot circular sewer and a 5 by 7 ft. 6-in. egg-shaped sewer have nearly the same area of cross-section. If both are laid to a 0.2 per cent grade, find the discharge and velocity of each when flowing full. (NOTE: Solve by Figs. 28 and 29. See *A*, above.)

Answer. Discharge, 165 cu. ft. per second; and velocity, 5.8 ft. per second, for the circular sewer; and discharge 163 cu. ft. per second; and velocity, 5.7 ft. per second, for the egg-shaped sewer.

NOTE: Although the egg-shaped sewer has a slightly smaller velocity when both are flowing full, it has a materially greater velocity than the circular sewer for small depths of flow.

Example 14. If the minimum allowable velocity of flow in storm sewers is 3 ft. per second, find the minimum allowable grades for 2 ft. by 3 ft., 4 ft. by 6 ft., and 6 ft. by 9 ft. egg-shaped sewers, respectively.

Answer. See *C*, above. 0.20, 0.08, and 0.05 per cent, respectively.

43. Diagram of Discharges and Velocities in Circular Sewers at Different Depths of Flow. The diagrams so far given show the discharges and velocities in sewers *flowing full.* It often, however, is necessary to be able to calculate the discharge and the velocity when the sewer flows only *partially* full.

For *circular sewers,* the discharges and velocities, when flowing only *partially full,* can readily be determined by the use of the diagram, Fig. 30, in connection with Figs. 27 and 28.

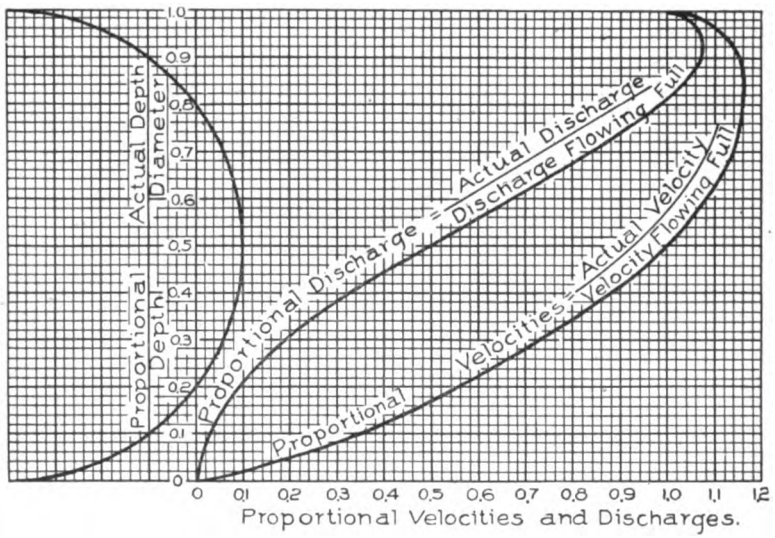


Fig. 30. Diagram Showing Changes in Velocity and Discharge in Circular Sewers for Different Depths of Flow.

TO USE THE DIAGRAM

(A) *When the depth of flow is given, together with the diameter and grade of the sewer, to determine the discharge and the velocity.*

(1) By Fig. 27 if a pipe sewer, or by Fig. 28 if a brick or concrete sewer, determine the *discharge* and *velocity* of the sewer *flowing full.* (2) Divide the given depth of flow by the given diameter, to determine the *proportional depth* of flow; and find this proportional depth on the vertical scale towards the left of Fig. 30, interpolating by the eye, if necessary. (3) Find the intersection of the horizontal line through the proportional depth (found in 2, above), first, with the *proportional discharge line,* and, second, with the *proportional velocity line,* in Fig. 30; and read off at the bottom of the diagram vertically below these intersection points, the *proportional discharge* and the *proportional velocity.* (4) Multiply the *discharge and velocity flowing full* (found in 1, above), by the *proportional discharge* and *proportional velocity*

found in 3, above), and the products will be the required *actual discharge and actual velocity, for the given depth of flow.*

(*B*) *When the actual discharge is given, together with the diameter and grade of the sewer, to find the depth and velocity of flow.*

(1) By Fig. 27 if a pipe sewer, or by Fig. 28 if a brick or concrete sewer, determine the *discharge of the sewer flowing full.* (2) Divide the given discharge by the discharge flowing full, to determine the *proportional discharge*; and find this along the bottom of the diagram in Fig. 30, interpolating by the eye, if necessary. (3) Find the intersection of the vertical line through the proportional discharge (found in 2, above) with the *proportional discharge curve* in Fig. 30; and horizontally to the left, read off on the vertical scale near the left of the diagram the *proportional depth* of flow. (4) Multiply the diameter of the sewer by the proportional depth, and the product will be the *actual depth of flow for the given discharge.* (5) The actual velocity can now be found as described above for case *A*.

All other cases than *A* and *B* can be readily solved by similar obvious methods.

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Example 15. What will be the actual discharge and velocity of flow in a 48-inch circular brick sewer laid to a 0.15 per cent. grade, and flowing 6 inches deep?

Solution. See *A*, above. (1) By Fig. 28, with the sewer flowing full, the discharge would be 30,000,000 gallons per day, and the velocity 3.8 ft. per second. (2) $\frac{6 \text{ inches}}{48 \text{ inches}} = 0.12 + =$ proportional depth of flow, which we find on the vertical scale near the left of Fig. 30. (3) Horizontally opposite the point found in 2, we locate points on the proportional discharge curve and the proportional velocity curve in Fig. 30; and vertically beneath these points we read at the bottom of the diagram, 0.04 = proportional discharge, and 0.40 = proportional velocity. (4) $0.04 \times 30{,}000{,}000$ gallons = 1,200,000 gallons per day = actual discharge for 6 inches depth of flow; and $0.40 \times 3.8 = 1.5$ ft. per second = actual velocity for 6 inches depth of flow.

Example 16. An 8-inch pipe sewer, laid to a 0.40 per cent grade, is to carry the sewage of 500 people contributing 100 gallons each per day. What will be the average depth and velocity of flow?

Solution. See *B*, above. (1) By Fig. 27, the discharge and velocity flowing full would be respectively 450,000 gals. per day, and 1.9 ft. per second. (2) The actual discharge is $500 \times 100 = 50{,}000$ gals. per day, and hence the *proportional discharge* is $\frac{50{,}000}{450{,}000} = 0.11$. We find this proportional discharge along the bottom line of Fig. 30, interpolating by eye. (3) Vertically above the 0.11 proportional velocity,

we find a point on the proportional discharge curve; and tracing horizontally to the left, we there read off the proportional depth = 0.225. (4) $0.225 \times 8 = 1.8$ inches = the actual depth of flow for the given discharge. (5) Horizontally to the right from the 0.225 proportional depth, we find a point on the proportional velocity line; and vertically beneath this point we read off at the bottom of the diagram, proportional velocity = 0.60. Then 0.60×1.9 (see 1, above) = 1.1 ft. per second = actual velocity for the given depth.

Example 17. What will be the discharge and velocity of a 12-inch pipe sewer laid to a 0.25 per cent grade when flowing 4 inches deep?

See *A*, above.

Answer. Discharge, 250,000 gals. per day; velocity, 1.7 ft. per second.

Example 18. What will be the depth and velocity of flow in a

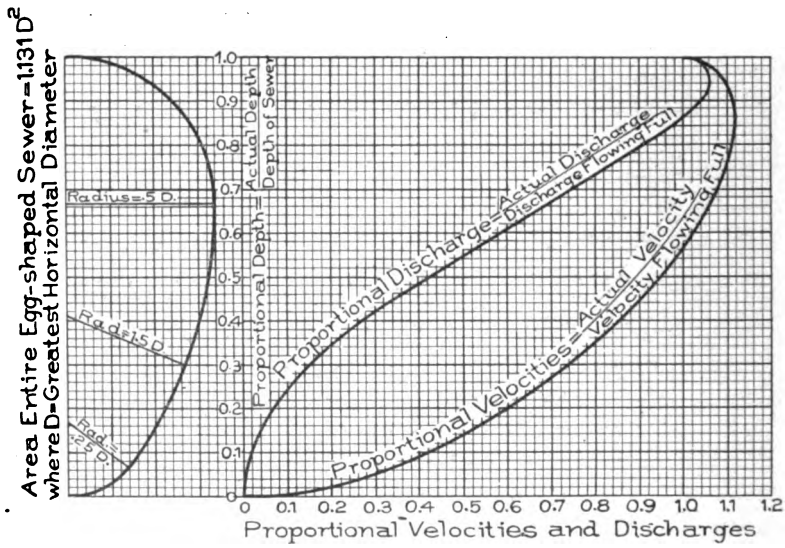


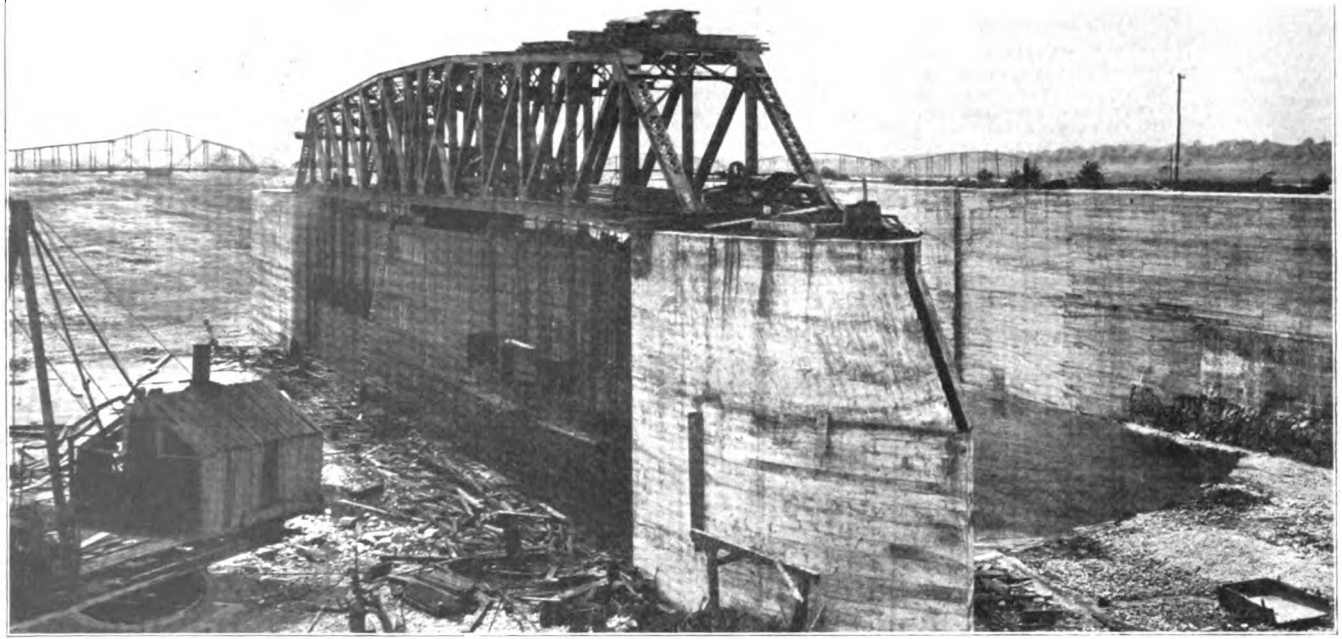
Fig. 31. Diagram Showing Changes in Velocity and Discharge in Egg-Shaped Sewers for Different Depths of Flow.

15-inch pipe sewer, laid at a 0.2 per cent grade, carrying 1,000,000 gallons of sewage per day?

See *B*, above.

Answer. Depth, 8 inches; velocity, 2.3 ft. per second.

44. Diagram of Discharges and Velocities in Egg-Shaped Sewers at Different Depths of Flow. For egg-shaped sewers, the discharges and velocities, when flowing *partially full*, can readily be determined by the diagram, Fig. 31, used in connection with Fig. 29.



"BUTTERFLY" DAM, CHICAGO DRAINAGE CANAL, LOCKPORT, ILL.

Ordinarily the dam is open, the movable leaf, shown under the bridge, pointing up and down stream. This leaf swings on a central pivot and, when once started by rack and pinion throwing it into the current, swings across the channel, closing it automatically, the small gates in one arm of the leaf being closed while those in the other arm are left open, thus varying the pressure on the two arms. The leaf may be swung back automatically by simply reversing the operation of the small gates, closing those that were before open, and *vice versâ*.

Isham Randolph, Chief Engineer.

TO USE THE DIAGRAM

(*A*) *When the depth of flow is given, together with the diameter and grade of the sewer, to determine the discharge and the velocity.*

(1) By Fig. 29, determine the *discharge and velocity* of the sewer *flowing full.* (2) Divide the given depth of flow by the given height to determine the *proportional depth* of flow, and find this proportional depth on the vertical scale towards the left of Fig. 31, interpolating by the eye, if necessary. (3) Find the intersection of the horizontal line through the proportional depth (found in 2, above), first, with the *proportional discharge line,* and, second, with the *proportional velocity* line, in Fig. 31; and read off at the bottom of the diagram, vertically below these intersection points, the *proportional discharge,* and the *proportional velocity.* (4) Multiply the *discharge and velocity flowing full* (found in 1, above), by the *proportional discharge and proportional velocity* (found in 3, above), and the products will be the required *actual discharge and actual velocity for the given depth of flow.*

(*B*) *When the actual discharge is given, together with the diameter and grade of the sewer, to find the depth and velocity of flow.*

(1) By Fig. 29, determine the *discharge of the sewer flowing full.* (2) Divide the given discharge by the discharge flowing full, to determine the *proportional discharge,* and find this along the bottom of the diagram in Fig. 31, interpolating by the eye, if necessary. (3) Find the intersection of the vertical line through the proportional discharge (found in 2, above), with the *proportional discharge curve* in Fig. 31, and horizontally to the left, read off on the vertical scale near the left of the diagram the *proportional depth* of flow. (4) Multiply the height of the sewer by the proportional depth, and the product will be the *actual depth of flow for the given discharge.* (5) The actual velocity can now be found as described above for case *A*.

All other cases than *A* and *B* can be readily solved by similar obvious methods.

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Example 19. What will be the discharge and velocity in an egg-shaped brick or concrete sewer 3 ft. by 4 ft. 6 in., laid to a 0.15 per cent grade, and flowing 12 inches deep?

See *A*, above.

Solution. (1) By Fig. 29, discharge and velocity flowing full = 36 cu. ft. per second, and 3.45 ft..per second, respectively. (2) The proportional depth $= \frac{12}{54} = 0.22$, which we find at left of Fig. 31. (3) We locate the intersections of the horizontal line through the 0.22 proportional depth with the proportional discharge and proportional velocity curves, respectively; and vertically below these points we read off, at the bottom of the diagram, proportional discharge = 0.08, and proportional velocity = 0.63. (4) $36 \times 0.08 = 2.9$ cu. ft. per second = actual discharge; $3.45 \times 0.63 = 2.2$ ft. per second = actual velocity.

Answer. Discharge = 2.9 cu. ft. per second; velocity = 2.2 ft. per second.

Example 20. What will be the depth and velocity of flow in an egg-shaped brick or concrete sewer 5 ft. by 7 ft. 6 in. dimensions, laid to a 0.10 per cent grade, and carrying 30 cu. ft. per second flow of sewage?

See *B*, above.

Solution. (1) By Fig. 29, the discharge and velocity flowing full = 117 cu. ft. per second and 4.05 ft. per second, respectively. (2) Proportional discharge $= \frac{30}{117} = 0.26-$, which find at bottom of Fig. 31. (3) Vertically above the 0.26 proportional discharge, we locate a point on the proportional discharge curve in Fig. 31, and horizontally to the left from this point read off the proportional depth = 0.39. (4) $90 \times 0.39 = 35$ inches = actual depth of flow. (5) Horizontally to the right along the 0.39 proportional depth line, we locate a point on the proportional velocity line; and vertically beneath this, we read off, at the bottom of the diagram, proportional velocity = 0.845. Then $4.05 \times 0.845 = 3.4$ ft. per second = actual velocity.

Answer. Depth of flow = 35 inches; velocity = 3.4 ft. per second.

Example 21. What will be the discharge and velocity in an egg-shaped brick or concrete sewer 2 ft. by 3 ft. dimensions, laid to a 0.50 per cent grade, flowing 18 inches deep?

See *A*, above.

Answer. Discharge = 5,900,000 gals. per day; velocity = 4.5 ft. per second.

Example 22. What will be the depth and velocity of flow in an egg-shaped brick or concrete sewer 3 ft. 6 in. by 5 ft. 3 in. dimensions, laid to a 0.08 per cent grade, carrying 25 cu. ft. per second of sewage?

See *B*, above.

Answer. Depth of flow = 39 inches; velocity of flow = 2.9 ft. per second.

GENERAL EXAMPLES FOR PRACTICE WITH FIGS. 27-31

45. The solution of the following general examples will further familiarize the student with the principles thus far explained.

Example 23. A 24-inch sewer is to be laid to a 0.25 per cent grade, and may be made of vitrified sewer pipe or of brick. Compare the discharges and velocities obtained with the two materials. (NOTE: Use Figs. 27 and 28.)

Answer. With sewer pipe, discharge = 7,200,000 gals. per day; velocity = 3.6 ft. per second.

With brick, discharge = 6,000,000 gals. per day; velocity = 3 ft. per second.

Example 24. A combined sewer, laid to a 0.15 per cent grade, drains an area requiring either a 3-foot circular or a 2 ft. 6 in. by 3 ft. 9 in. egg-shaped brick sewer. (These sizes have the same cross-sectional area, and nearly the same discharges and velocities, when flowing full.) The dry-weather flow of sewage will be only 1,000,000 gallons per day. Calculate the dry-weather depth and velocity of flow with each design. (NOTE: Use Figs. 28 and 30, and Figs. 29 and 31.)

Answer. With circular sewer, depth = 6.1 inches; velocity = 1.6 ft. per second.

With egg-shaped sewer, depth = 9.2 inches; velocity = 1.9 ft. per second.

Example 25. In a 10-inch pipe sewer, laid to a one per cent grade, the maximum depth of flow observed was 7 inches; and the minimum, 2 inches. What were the corresponding discharges? (NOTE: Use Figs. 27 and 30.)

Answer. Maximum discharge = 1,100,000 gals. per day;
Minimum " = 120,000 " " "

Example 26. What size of circular sewer laid to a 0.08 per cent grade will be required to carry the sanitary sewage of a city of 100,000 population, with an average flow of sewage of 150 gallons per capita per day, the maximum rate of flow being three times the average?

Answer. 5 ft. 3 in. diameter.

Example 27. What size of egg-shaped combined sewer, laid to a 0.07 per cent grade will be required to carry a storm sewage flow of 0.5 cu. ft. per second per acre from a drainage area of 320 acres?

Answer. 6 ft. by 9 ft.

46. Summary of Laws of Flow in Sewers. The principles discussed in Articles 38 to 44, inclusive, may be briefly summarized as follows:

(1) The laws of flow for sewage are the same as for water.

(2) Kutter's formula is generally considered most reliable for calculating the flow in sewers, though complicated to use directly.

(3) In Kutter's formula, the values of the coefficient of roughness generally used for sewer computations, are $n = 0.013$ for pipe sewers, and $n = 0.015$ for brick and concrete sewers.

(4) Sewer diagrams greatly simplify sewer computations, and are presented in Figs. 27 to 31, inclusive, for circular and egg-shaped sewers, with full instructions for use.

(5) In Fig. 30, the laws of flow for different depths of flow in

circular sewers are shown. An examination of the diagram brings out this important law:

In circular sewers flowing half-full, the velocity is the same as when the sewer flows full; and hence the discharge flowing half-full is just half the discharge flowing full.

(6) Figs. 30 and 31 also show the following important law of flow:

In a sewer of any shape, not flowing under pressure, the maximum discharge and velocity will occur, not with the sewer flowing full, but with it flowing a little less than full.

This is due to the increased friction against the top of the sewer when it flows full. Owing to this law, no sewer can flow full without being under pressure.

(7) In the case of combined sewers having a dry-weather flow very small as compared with the storm flow, egg-shaped sewers give materially greater depths and velocities of dry-weather flow than circular sewers.

CALCULATIONS OF SIZES AND MINIMUM GRADES OF SEPARATE SANITARY SEWERS

47. Minimum Sizes of Sanitary Sewers. In the early construction of sewers, previous to the last half of the 19th century, the laterals and sub-mains were usually made very much larger than the amount of sewage would require, with the idea, apparently, that the bigger the sewer the better. Such badly proportioned sewers were in great danger of stoppages from the inability of the shallow, trickling stream to carry along the solid matter. In fact, the sewers were expected to form deposits, and were purposely made large to hold a large amount of deposit and to enable men to enter for the purpose of cleaning them. Disastrous sanitary experience with such foul sewers made it apparent that there was just as much danger from making the sewers too large as from making them too small, especially in the case of sanitary sewers. Such sewers should be made small enough to give a good depth and velocity of flow.

Sanitary sewers should not be made small enough, however, to cause frequent stoppages by catching articles which have been admitted into them through the house connections. House owners are often reprehensibly negligent in putting into their plumbing fixtures,

articles which should be carefully excluded. On this account, the size of house connections should be restricted to 4 inches.

An 8-inch sewer pipe will practically always carry freely, even crosswise, any article which can come lengthwise around the traps and bends in 4-inch soil-pipes and house connections Hence *eight inches should usually be adopted as the minimum size for sanitary sewers.*

Usually the great bulk of the sanitary sewers in a separate system will be of this minimum size, only a limited length of the larger sizes being required for sub-mains and mains. See the sewerage map of Ames, Iowa, Fig. 38.

In the early use of the separate system, many 6-inch laterals were constructed, and, except for occasional stoppages from articles improperly put into the sewers, they have worked well. Some engineers still use six inches as the minimum size.

48. Minimum Grades and Velocities for Separate Sanitary Sewers. In the design and construction of sewers it has been found that certain minimum grades should be adopted to prevent deposits, no sewers being built to lighter grades than the minimum unless special means for flushing, or special facilities for cleaning, are provided. This is to insure sufficient velocity to prevent the settling out of the solid matter in the sewage to form deposits in the sewers.

These minimum grades for separate sanitary sewers are as follows:

TABLE II
Minimum Grades for Separate Sanitary Pipe Sewers

Diameter	Minimum Grade	Diameter	Minimum Grade
4 inches	1.20 per cent	18 inches	0.12 per cent
6 "	0.67 " "	20 "	0.10 " "
8 "	0.43 " "	24 "	0.08 " "
9 "	0.36 " "	27 "	0.07 " "
10 "	0.30 " "	30 "	0.06 " "
12 "	0.23 " "	33 "	0.05 " "
15 "	0.16 " "	36 "	0.045 " "

Caution.—*For the above minimum grades to be satisfactory and safe, there must be enough sewage to give a good depth of flow.*

The flow and velocity in a sewer fluctuate greatly, as illustrated in Article 52, below, the velocity at low flow being much less than when flowing full or half-full.

Experiments have shown that an actual velocity of 1¼ to 1½ feet per second is sufficient to prevent deposits of the solid matters usually found in sanitary sewers; but to secure this velocity at low flow requires about 2 feet per second when the sewer flows full or half-full (see Figs. 30 and 31 for the fluctuation of velocity with depth of flow). Hence *the minimum grades for sanitary sewers should usually be those giving a velocity of 2 feet per second when flowing full or half-full, as shown by the diagrams, Figs.* 27, 28, *and* 29.

It is usually considered that, within a reasonable period in the future, the increased high-water flow each day should be sufficient to fill the sewer half-full or nearly so. However, in numerous cases, sanitary sewers have been observed to work well at the above grades with less depths of flow than this.

Much will depend on the nature of the sewage. Some thick, manufacturing sewages, heavily loaded with solid matter, would require considerably heavier grades to insure self-cleansing.

Where it is absolutely impossible to secure the above minimum grades, special means for flushing, such as automatic flush-tanks placed about three blocks apart, should be used.

49. General Explanation of the Calculation of Amount of Sanitary Sewage. The first thing necessary in computing the size required for any particular sanitary sewer, is to ascertain the amount of sewage it must carry. While this cannot be foretold with exactness, yet, by well-established methods, an approximation sufficiently close for all practical purposes can readily be made.

The *first step* in computing the amount of sewage will be to estimate the future tributary population which may use the sewer. For this, see Art. 50, below.

The *second step* will be to estimate the average amount of sewage contributed by each person per day—that is, the average flow of sewage per capita per day. This, multiplied by the tributary population, will give the total average amount of sewage per day which the sewer must carry.

Two methods are in use for estimating the average flow of sewage per capita per day:

(1) It is often assumed to equal the average consumption of water per capita per day. For this method, see Art. 51, below.

(2) The best method is to compare the local conditions with

actual sewer gaugings of flow in sewers under similar conditions elsewhere. For this method, see Art. 52, below.

50. Methods of Estimating the Population Tributary to Sanitary Sewers. The most important difficulty encountered in estimating the population tributary to sanitary sewers, is the fact that it is the *future* population which must be determined. To know the present tributary population is not sufficient. Two methods will be described:

(1) *The best method of estimating the future population tributary to sanitary sewers is as follows*:

(*a*) On the sewer map, lay out sewers to serve all districts to be served in the future as well as at present.

(*b*) After careful examination of the ground, and study of the conditions, estimate the number of persons tributary to the sewers per 100 feet of sewers in each district when it is built up as fully as can reasonably be expected.

In doing this, five or six persons per family should usually be allowed, and the number of families on both sides of the street for one block in the future estimated. The number of persons per block so obtained should then be divided by the number of hundred feet of sewer per block from center to center of streets.

Thus, if there are 6 lots 50 feet wide per block (=300 feet) on each side of the sewer, and the streets are 60 feet wide (=360 feet center to center of streets), and if it is thought that every lot will eventually contain one residence,

$$\text{Tributary population} = \frac{12 \times 6 \text{ persons}}{3.60} = 20 \text{ persons per 100 feet of sewer.}$$

The tributary population per 100 feet of sewer will usually range from 20 persons in the residence districts of small cities, to 100 persons in thickly built-up business districts. In the congested districts of the largest cities, the population is still denser.

(*c*) *To determine the total population tributary above any point on a sanitary sewer, scale from the sewer map the total number of hundred feet of tributary sewer above that point, including all branches; and multiply the total so obtained by the tributary population per* 100 *feet of sewer.*

Thus, if there are 15,600 ft. of tributary sewers, and the tributary population is 20 per 100 ft., the total tributary population will = 85 × 20 = 1,700 persons. In some cases part of the length of tributary

sewers may have to be multiplied by one density of tributary population, and part by another.

(2) In case the future population of an entire city is to be estimated, a different method must be used.

Usually, the past population of the city at different dates is obtained from census reports; and by study of this past growth, and of the present and probable future local conditions as affecting growth, and by comparison with the past growth of larger cities whose conditions were similar, estimates are made of the probable future populations at different dates, for 20 to 50 years in the future.

Usually, also, the past records of the city that is being studied, and of others, are platted as curves on cross-section paper, the ordinates representing population, and the abscissæ dates; and the future estimates are made by prolonging the curve of growth into the future.

51. Use of Statistics of Water Consumption in Determining the Per Capita Flow of Sanitary Sewage. Since about 99.8 per cent of sanitary sewage is merely ordinary water, nearly always taken from the public supply, the total flow per capita of sanitary sewage is usually approximately equal to the consumption of water per capita (that is,

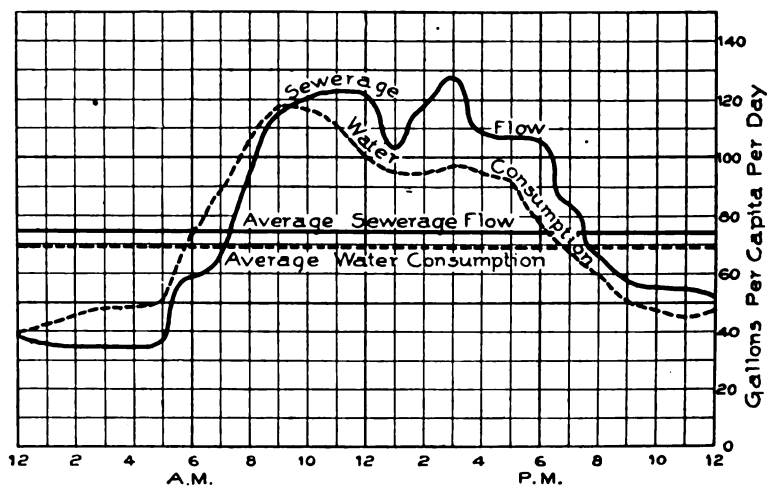


Fig. 32. Typical Gauging of Flow of Sanitary Sewage, Des Moines, Iowa, Friday, July 5, 1895.

per person). In Fig. 32 may be seen how closely sewage flow and water consumption ordinarily correspond.

In many towns, however, there will not be such close correspondence. Sometimes considerable amounts of water may be used for manufacturing or other purposes which divert it from the sewers, making the sewage flow less than the water consumption. More often there will be considerable influxes of ground water through leaking sewer joints, sometimes making the sewage flow several times as great as the water consumption.

However, very extensive statistics of water consumption in a large number of places have been collected, while actual gaugings of flow of sewage are comparatively few. Hence statistics of the water consumption of the town for which sewers are being designed, or of similar towns elsewhere, are often used as the basis for estimating the per capita flow of sanitary sewage. In studying each town

TABLE III

Consumption of Water in American Cities, 1895

City	Population	Daily Consumption per Person, 1895. Gallons
New York	3,437,202	100
Chicago	1,698,575	139
Philadelphia	1,293,697	162
St. Louis	575,238	98
Boston	560,892	100
San Francisco	342,782	63
Buffalo	352,387	271
New Orleans	287,104	35
Minneapolis	202,718	88
Columbus	125,560	127
Atlanta	89,872	42
Nashville	80,865	139

preliminary to designing sewers for it, all possible information should be secured relative to its water consumption.

On pages 4 to 10 of the instruction paper on Water Supply, Part I, will be found a detailed discussion of water consumption. From a larger table given there, Table III herewith is condensed, to show how the average per capita water consumption varies in different American cities.

It will be noted that there is a very wide range in water consumption. The excessively low rates usually mean an incomplete water supply, which is likely to be extended later, while the excessively high rates usually mean great waste of water. This can often be greatly reduced by introducing water meters.

Under fairly average conditions the consumption will usually fall between the limits of 40 and 125 gallons per capita per day, as shown in detail in Table IV.

TABLE IV

Water Consumption under Ordinary Conditions

Use	Gallons per Capita per Day		
	Minimum	Average	Maximum
Domestic	15	25	40
Commercial	7	20	35
Public	3	5	10
Waste and Loss	15	25	40
Total	40	75	125

52. Use of Sewer Gaugings in Determining the Per Capita Flow of Sanitary Sewage. It has already been stated that the flow of sanitary sewage is not always equal to the water consumption. In one case of sewer gaugings, the writer found the flow of sewage to be only 50 to 60 per cent of the water consumption, the remainder of the water being consumed for purposes which diverted it from the sewers. In another case of sewer gaugings, the writer found the flow of sewage to be over 500 per cent of the water consumption, the increase being due to infiltration of ground water through sewage joints. Hence, water consumption data alone are not sufficient in making estimates of sewage flow, and data from actual sewer gaugings are needed. Of late years there is an increasing accumulation of data of sewage flow obtained from actual gaugings. Some of these data are given in Table V.

At the Iowa State College, the sewage flow, as given in Table V, below, was 50 to 60 per cent of the water consumption, owing to uses of water which diverted it from the sewers. At Grinnell, on the other hand, infiltration of ground water into the sewers increased the sewage flow to about six times the total water consumption on the same day.

A study of Table V will show, however, that *in general the average flow of sanitary sewage is between the limits of* 50 *and* 125 *gallons per capita per day.*

53. Capacities of Sanitary Sewers Required to Provide for Fluctuations in the Rate of Flow. So far our discussion of flow of

TABLE V
Gaugings of Flow of Sanitary Sewage

Sewer	Date	Duration, Days	Tributary Population	Sewage Flow, Gals. per Capita per Day		
				Min.	Av.	Max.
Compton Ave., St. Louis	1880	6	8,200	65	102	149
College St., Burlington, Vt.	1880	5–8	325	65	115	140
Huron St., Milwaukee, Wis.	1880	–	3,174	—	—	120
Memphis, Tenn.	1881	–	20,000	61	—	140
13 Sewers, Providence, R. I.	1884	1–6	33,825	—	78	—
Asylum, Binghamton, N. Y.	1888	–	1,300	—	—	608
16 Sewers, Toronto, Ont.	1891	3	168,081	—	87	—
Insane Asylum, Weston, W. Va.	1891	2	1,000	40	91	151
Schenectady, N. Y.	1892	1	*10,000	72	86	103
Canton, Ohio	1893	–	40,000	54	129	180
Chautauqua, N. Y.	1894	–	7,000	6	20	30
Iowa State College, Ames, Ia.	1894	7	289	0	32	77
Des Moines, Ia., E. Side	1895	15	8,100	22.5	74	142
Des Moines, Ia., W. Side	1895	13	19,400	23.2	66	175.3
Iowa State College, Ames, Ia.	1900	2	800	54	95	175
Iowa State College, Ames, Ia.	1900	28	800	30	57	130
Marshalltown, Ia.	1900	1	4,200	67	85	111
Grinnell, Ia.	1901	1	2,000	169	186	200
Insane Asylum, Mt. Pleasant, Ia.	1901	1	1,200	32	62	115
Waverly, N. Y.	1905	4	1,796	79	155	194

* Estimated.

sanitary sewage (Arts. 51 and 52) has referred particularly to the *average* flow per capita per day. The flow, however, is not uniform, but fluctuates greatly. First, there is a *seasonal fluctuation.* The flow is apt to be especially high in severe cold weather, when faucets are left running to keep pipes from freezing; in hot weather, when water consumption is high; and in wet weather, when some ground water finds its way into the sewers.

Second, there is a *daily fluctuation.* For example, gaugings show that the flow usually is light on Sundays and holidays, when business is suspended. The flow on Monday is apt to be especially high, on account of wash day.

Third, there is an *hourly fluctuation*, at different times of the day and night. In Fig. 32, an example is shown of the fluctuation of sewage flow throughout one day, as determined by a continuous sewer gauging in the case of a city of 56,000 population. As shown in this figure, the flow of sanitary sewage is usually low through the night, reaching a minimum at about 2 to 3 A. M. It increases rapidly early in the morning, reaching a high point at about 10 to 11 A. M. Although there is usually a temporary drop at the noon

hour, the flow continues high until early evening, and then decreases rapidly to its low night value.

A study of the sewer gaugings summarized in Table IV, together with others, shows that the flow of sanitary sewage ordinarily fluctuates from a minimum rate of 30 per cent to a maximum rate of 265 per cent of the average rate. If the gaugings had been extended over longer periods of time, still greater fluctuations of flow would certainly have been found.

It is apparent that the fluctuations in rate of flow will be greater in lateral sewers than in main sewers. To make them large enough to provide for the greatest rates of flow to be reasonably expected, *sanitary sewers should be given the following capacities*:

PROPER CAPACITIES OF SANITARY SEWERS

For lateral sewers, 350 per cent of the average flow.
For sub-main sewers, 325 per cent of the average flow.
For main sewers, 300 per cent of the average flow.

Table VI (page 68) is proportioned on the above basis.

54. Ground Water in Sanitary Sewers. In addition to the sanitary sewage itself, provision must often be made in separate sanitary sewers for leakage of ground water into the sewers. The amount of ground water to be allowed for, will depend on the character of the soil, on the height of the ground water with reference to the sewer, and on the care with which the sewer joints are made. *If the joints are made very carefully, the amount of ground water to be expected may range, with the soil, and height of ground water, from* 0 *to* 30,000 *gallons per mile.* This will constitute, say, 0 to 30 per cent of the sewage, but is a steady flow, not requiring the 300 to 350 per cent allowance for fluctuations required for sewage (see Art. 53). Hence, *if the joints are carefully made, the capacity of the sewers need not be increased more than* 10 *per cent for ground water.*

If sub-drains with outlets separate from the sewers are provided for all wet stretches of trench, no allowance whatever for ground water need be made in the size of the sewers.

The infiltration of ground water is apt to be much greater during and immediately after the construction of sewers than later, for the effect of sewers is to lower permanently the level of the ground water.

55. Summary of Methods of Computing Sizes of Separate Sanitary Sewers. The methods for computing the sizes of sanitary sewers may be summarized as follows:

(1) Lay out on the sewer map all the sewers required to serve all districts which can reasonably be expected to be included in the system, either at present or within say 30 to 50 years in the future.

(2) By a careful study of the topography, business conditions, manufacturing possibilities, and other future prospects, together with the sizes of blocks and lots, and the widths of streets, determine the probable future tributary population in each district per 100 feet of sewer, allowing usually five or six persons per family.

(3) By a careful study of the statistics of water consumption (Art. 51), and by comparison with actual sewer gaugings (Art. 52), taking into account all local conditions, estimate the average flow of sewage in gallons per capita per day.

(4) Beginning at the upper ends of the sewers, scale from the map and tabulate the total lengths of tributary sewer above successive points in the system, to the outlet. Multiply the number of hundreds of feet in these lengths by the tributary population per 100 feet, and by the average per capita flow of sewage per day, to get the total flow of sanitary sewage at the successive points.

(5) To allow for fluctuations (Art. 53), multiply the above average rates of flow of sanitary sewage by

$3\frac{1}{2}$ for lateral sewers;
$3\frac{1}{4}$ " sub-main "
3 " main "

to get the maximum rates of flow of sanitary sewage.

(6) To the maximum rates of flow so found, add 0 to 30,000 gallons per mile of tributary sewers, to allow for ground water (Art. 54).

(7) Occasionally it may be necessary also, in the case of certain sewers, to make special allowances for manufacturing sewage from large factories, each factory being studied by itself to determine its probable sewage flow. This flow will usually be subject to as much fluctuation as sanitary sewage, and hence must be multiplied by the factors given in 5, above.

(8) On the sewer profiles (see Art. 92), the grades of the sewers at the successive points will be determined and shown. Using these grades, and the total maximum rates of flow of sewage determined

TABLE VI
Sizes Required for Separate Sanitary Pipe Sewers

1	2	3	4	5	6	7	8	9
Diam. of Sewer, Ins.	Grade of Sewer, %	Maximum Permissible Av. Flow, Gals. per Day	Maximum Permissible Tributary Population			Maximum Permissible Linear Feet of Tributary Sewer for 20 Persons per 100 Feet		
			Gals. per Capita per Day			Gals. per Capita per Day		
			75	100	125	75	100	125
8	0.43	130,000	1,700	1,300	1,000	8,700	6,500	5,200
	0.60	160,000	2,100	1,600	1,300	11,000	8,000	6,400
	0.80	180,000	2,400	1,800	1,400	12,000	9,000	7,200
	1.00	200,000	2,700	2,000	1,600	13,000	10,000	8,000
	1.40	240,000	3,200	2,400	1,900	16,000	12,000	9,600
10	0.30	220,000	2,900	2,200	1,800	15,000	11,000	8,800
	0.40	260,000	3,400	2,600	2,100	17,000	13,000	10,000
	0.60	310,000	4,100	3,100	2,500	21,000	15,000	12,000
	0.80	360,000	4,800	3,600	2,900	24,000	18,000	14,000
	1.00	400,000	5,300	4,000	3,200	27,000	20,000	16,000
12	0.23	350,000	4,700	3,500	2,800	23,000	17,000	14,000
	0.40	460,000	6,100	4,600	3,700	31,000	23,000	18,000
	0.60	560,000	7,500	5,600	4,500	37,000	28,000	22,000
	0.80	650,000	8,700	6,500	5,200	43,000	32,000	26,000
	1.00	720,000	9,600	7,200	5,800	48,000	36,000	29,000
15	0.17	550,000	7,300	5,500	4,400	37,000	27,000	22,000
	0.30	750,000	10,000	7,500	6,000	50,000	37,000	30,000
	0.40	850,000	11,000	8,600	6,900	57,000	43,000	34,000
	0.60	1,000,000	13,000	10,000	8,000	67,000	50,000	40,000
	0.80	1,200,000	16,000	12,000	9,600	80,000	60,000	48,000
18	0.13	800,000	11,000	8,000	6,400	55,000	40,000	32,000
	0.30	1,200,000	16,000	12,000	9,600	80,000	60,000	48,000
	0.40	1,400,000	19,000	14,000	11,000	93,000	70,000	56,000
	0.60	1,700,000	23,000	17,000	14,000	113,000	85,000	68,000
	0.80	2,000,000	27,000	20,000	16,000	134,000	100,000	80,000
24	0.10	950,000	12,000	9,500	7,400	62,000	46,000	37,000
	0.20	1,300,000	17,000	13,000	10,000	87,000	65,000	52,000
	0.40	1,900,000	25,000	19,000	15,000	126,000	95,000	76,000
	0.60	2,300,000	31,000	23,000	18,000	153,000	115,000	92,000
	0.80	2,600,000	35,000	26,000	21,000	173,000	130,000	104,000
27	0.08	1,400,000	19,000	14,000	11,000	93,000	70,000	56,000
	0.20	2,200,000	29,000	22,000	18,000	147,000	110,000	88,000
	0.30	2,700,000	36,000	27,000	22,000	180,000	135,000	108,000
	0.40	3,100,000	41,000	31,000	25,000	207,000	155,000	124,000
	0.60	3,800,000	51,000	38,000	30,000	254,000	190,000	152,000
30	0.06	2,200,000	29,000	22,000	18,000	147,000	110,000	88,000
	0.10	2,800,000	37,000	28,000	22,000	187,000	140,000	112,000
	0.20	4,000,000	53,000	40,000	32,000	267,000	200,000	160,000
	0.40	5,700,000	76,000	57,000	46,000	380,000	285,000	238,000
	0.60	7,000,000	93,000	70,000	56,000	466,000	350,000	280,000
36	0.05	3,200,000	43,000	32,000	26,000	214,000	160,000	128,000
	0.10	4,600,000	61,000	46,000	37,000	307,000	230,000	184,000
	0.20	6,500,000	87,000	65,000	52,000	433,000	325,000	260,000
	0.40	9,300,000	124,000	93,000	74,000	620,000	465,000	372,000
	0.60	11,400,000	152,000	114,000	91,000	760,000	570,000	456,000

in 5, 6, and 7, above, refer to Fig. 27 for pipe sewers, or to Fig. 28 for brick or concrete sewers, and find the sizes of sewers required.

Example 28. In a town in which the blocks are 340 feet, center to center of streets, there are 14 lots per block. The total length of tributary sewers above a certain point on a sub-main sewer in the system (separate sewers), is 16,600. The conditions affecting rate of sewage flow per capita are average. No allowance need be made for ground water or manufacturing sewage. The grade of the sewer is 0.30 per cent. What size is required?

Solution. The tributary population will be $\frac{14 \times 6}{3.4} = 25$ persons per 100 feet of sewer. The average rate of flow may be assumed at 85 gallons per capita per day. Hence the maximum rate of flow for this sub-main sewer will be $166 \times 25 \times 85 \times 3\frac{1}{4} = 1{,}150{,}000$ gallons per day.

Hence, by Fig. 27, for a 0.30 per cent grade, a 12-inch pipe sewer will be required.

Answer. A 12-inch pipe sewer.

56. Table of Sizes Required for Sanitary Sewers. By the methods given in Art. 55, omitting allowances for ground water and manufacturing sewage, Table VI (page 68) has been computed, to reduce the labor of computation of sizes of separate sanitary pipe sewers.

TO USE THE TABLE

Proceed to follow out steps 1, 2, 3, and 4, in Art. 55, just above (which read), thus determining the total estimated future number of linear feet of tributary sewer at successive points, the estimated future number of persons tributary per 100 feet of sewer (which let = P), and the estimated average flow of sewage in gallons per capita per day (which let = F). Also ascertain the grade to which the sewer is to be built.

(*A*) *If P = 20 persons per 100 feet, and if F lies between 75 and 125 gallons per capita per day, and if no allowance is necessary for ground water or manufacturing sewage*, find in column 7, 8, or 9, or by interpolating between them, according to the value of F, a number close to the calculated number of linear feet of tributary sewer opposite to the given sewer grade, interpolating between the grades, and take the corresponding size of sewer in column 1.

Example 29. For 13,100 linear feet of sewer, 20 persons per 100 ft., 85 gallons per capita per day, and 0.35 per cent grade.

We find that for a 0.35 per cent grade an 8-inch sewer would be considerably too small, as shown by interpolating between the numbers in columns 7 and 8, while a 10-inch sewer would be a little larger than needed.

Answer. A 10-inch pipe sewer.

(*B*) If P does not = 20 persons per 100 feet (the other conditions remaining as in *A*, above), first multiply the number of linear feet of tributary sewer by $\frac{P}{20}$, and then proceed as in *A*, just above.

Example 30. For 16,300 linear feet of sewer, 30 persons per 100 feet of sewer, 110 gallons per capita per day, and a sewer grade of 0.25 per cent.

We first find $16{,}300 \times \frac{30}{20} = 24{,}450$ linear feet. Then interpolating between columns 8 and 9, we find that for a 0.25 per cent grade a 12-inch would be considerably too small, while a 15-inch sewer is a little larger than needed.

Answer. A 15-inch pipe sewer.

(*C*) If F (rate of sewage flow) is less than 75 or more than 125 gallons per capita per day, first multiply the number of linear feet of tributary sewer by $\frac{F}{100}$, and then by $\frac{P}{20}$ (where P = persons per 100 feet of sewer), and then find the nearest number in column 8 opposite the given grade.

Example 31. For 22,500 linear feet of sewer, 35 persons per 100 feet, 150 gallons per capita per day, and 0.45 per cent grade.

We first find $22{,}500 \times \frac{150}{100} \times \frac{35}{20} = 59{,}000$ linear feet. In column 8 we find that for a 0.45 per cent grade a 15-inch sewer would be considerably too small, while an 18-inch is too large.

Answer. An 18-inch pipe sewer.

(*D*) *If ground water or manufacturing sewage, or both,* must be allowed for, ascertain the *total average sewage flow,* by multiplying the linear feet of tributary sewer by $\frac{P}{100}$ (P = persons per 100 feet), and this result by F (= gallons per capita per day, of sanitary sewage), and by then adding to this result the total allowance for manufacturing sewage, and $\frac{1}{3}$ the total allowance for ground water. Then find by interpolation in column 3 the nearest number opposite the given grade, and take the corresponding size of sewer.

Example 32. For 15,600 linear feet of tributary sewer, 25 persons per 100 feet, 85 gallons per capita per day, 15,000 gallons per day per mile ground water, 200,000 gallons per day manufacturing sewage, and 0.20 per cent grade.

We find the total average flow of sewage to use is $15{,}600 \times \frac{25}{100} \times 85 + 200{,}000 + \frac{15{,}000}{3} \times 3$ (miles) = 546,000 gallons per day. In column 3 we find that for a 0.20 per cent grade, a 12-inch sewer would be considerably too small, while a 15-inch is a little larger than is needed.

Answer. A 15-inch pipe sewer.

GENERAL EXAMPLE FOR PRACTICE IN DESIGNING SEPARATE SANITARY SEWERS

57. Working out the following example will materially help the student.

Example 33. Calculate the size of the outlet sewer of the sewer system shown in Fig. 4, assuming that there will be in the future 20 persons tributary per 100 feet of sewer, that the average flow of sewage will be 100 gallons per capita per day, no special allowance for ground water or manufacturing sewage being needed. Also assume that there may be in the future 15,000 feet of sewer extensions not shown in the figure. The grade of the outlet sewer is 0.20 per cent. Assume scale of drawing, 1,500 feet per inch.

Solution. Take a long strip of paper with one edge straight; and on this, mark off with a pencil a scale of feet from the scale assumed above. With this, scale off the lengths of all the sewers shown, except the storm sewers. Add up the lengths scaled, and add 15,000 linear feet of future extensions, to get the total length of tributary sewer. Then use Table VI.

Answer. An 18-inch pipe sewer.

CALCULATION OF SIZES AND MINIMUM GRADES OF STORM AND COMBINED SEWERS

58. Storm and Combined Sewers Calculated by Same Methods. In combined sewers the rate of flow of sanitary sewage is so small in time of storms in proportion to that of the storm sewage, that the sanitary sewage can be neglected altogether in calculating the size. For example, a combined sewer one mile long, with 20 persons tributary per 100 feet, and 75 gallons per capita per day, would have a maximum rate of flow of sanitary sewage at its lower end of $\frac{52.8 \times 20 \times 75 \times 3\frac{1}{2}}{7\frac{1}{2} \times 86{,}400} = 0.43$ cu. ft. per second (there being $7\frac{1}{2}$ gals. in 1 cu. ft., and 86,400 seconds in 1 day, and the maximum rate of flow being $3\frac{1}{2}$ times the average).

If the blocks are 360 feet wide, center to center of streets, this same sewer would have to take the storm sewage from $43\frac{1}{2}$ acres. The amount of this at the time of the maximum storm allowed for, calculated by the methods described below, would probably be at least 20 cu. ft. per second. The sanitary sewage would therefore be only about 2 per cent of the storm sewage. The amount of the latter cannot be foretold nearly so close as 2 per cent. Thus the sanitary sewage would have no appreciable effect upon the size of the combined sewer, and can be neglected.

59. Minimum Sizes of Storm and Combined Sewers. In the case of sanitary sewers, 8 inches was stated to be the minimum allowable diameter (see Art. 47); but in the case of sewers carrying storm sewage, there is much greater danger of stoppages from dirt, sticks, and other debris washed in from the surface during storms. Hence *twelve inches should be the minimum allowable diameter for storm and combined sewers.*

60. Minimum Grades and Velocities for Storm and Combined Sewers. It was stated in connection with sanitary sewers (Art. 48), that the minimum allowable velocities to prevent deposits should be

TABLE VII

Minimum Grades for Storm and Combined Sewers

Shape	Material	Size	Minimum Grades to Give Velocities of 3 ft. per Sec.	4 ft. per Sec.
Circular	Pipe	12-in. Diam.	0.48	0.88
"	"	15 "	0.34	0.62
"	"	18 "	0.25	0.47
"	"	24 "	0.17	0.31
"	"	30 "	0.13	0.23
"	Brick or Concrete	3-ft. "	0.14	0.25
"	"	4 "	0.10	0.17
"	"	5 "	0.07	0.12
"	"	6 "	0.06	0.10
"	"	7 "	0.05	0.08
"	"	8 "	0.04	0.06
"	"	9 "	0.03	0.05
"	"	10 "	0.025	0.045
Egg-Shaped	"	2 ft. × 3 ft.	0.20	0.35
"	"	2½ " × 3¾ "	0.15	0.26
"	"	3 " × 4½ "	0.12	0.20
"	"	4 " × 6 "	0.08	0.14
"	"	5 " × 7½ "	0.06	0.10
"	"	6 " × 9 "	0.05	0.08
"	"	7 " × 10½ "	0.04	0.07

1¼ feet per second at the minimum depths of flow, which will require grades sufficient to give minimum velocities of 2 feet per second when the sewer flows full or half-full. For sewers carrying storm sewage, however, greater minimum velocities are necessary to prevent deposits, on account of the dirt, pebbles, and other heavy rubbish washed into them from the surface in times of storms. *For combined and storm sewers the minimum allowable grades should be steep enough to give a minimum velocity of* 3 *feet per second. If practicable without too great expense,* 4 *feet per second should be secured.*

61. General Explanation of the Calculation of Amount of Storm Sewage. When rain begins to fall upon the area drained by a storm sewer, the water falling in the immediate neighborhood of the outlet at once enters the sewer and begins to be discharged. As time passes and the rain continues, water arrives at the outlet from more and more remote portions of the drainage area, and the discharge at the outlet increases quite rapidly until water is being discharged from all portions of the drainage area at the same time. After that, any further increase is slow, being due only to a per cent of run-off slowly increasing as the saturation of the soil becomes more complete.

The *time of concentration* is the longest time required for water from the remotest points of the portion of the drainage area being considered, to reach the outlet of that portion.

The *general law of the heaviest rainfalls*, the ones which determine the sizes of sewers, is that the heaviest rates for short storms are much greater than the heaviest rates for long storms. *The longer the time, the less will be the average rate of the maximum storm lasting that time.*

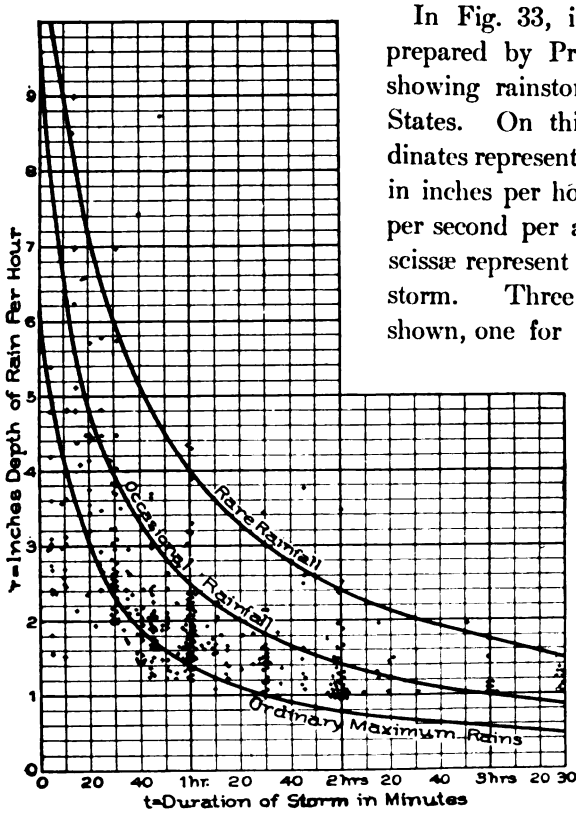


Fig. 33. Rates of Heavy Rainfall in the North Central States, Ohio, Indiana, Illinois, Missouri, Kansas, and Iowa.

In Fig. 33, is given a diagram prepared by Prof. A. N. Talbot, showing rainstorms in the Central States. On this diagram the ordinates represent the rate of rainfall in inches per hour (which = cu. ft. per second per acre), while the abscissæ represent the duration of the storm. Three curves are also shown, one for very rare rainfalls, one for ordinary heavy rains, and one intermediate. On the diagram each + represents one storm.

The storm causing the greatest rate of discharge in a storm sewer will usually be the maximum rain lasting a length of time equal to the time of concentration. If a time less than this be taken, water will not be discharged at the outlet from all parts of the drainage area at once, and that from near the outlet will have a chance to run away before that from the remotest points arrives. On the other hand, if a time be taken longer than the time of concentration, the *heaviest* rate of the maximum storm lasting this long will be less

than the rate of the maximum storm lasting a length of time just equal to the time of concentration; and since the storm is lighter the flow will be lighter.

Not all of the water falling on a drainage area will be carried away in the sewer. During and after the storm, some of the water is evaporated into the air, and some is absorbed into the soil. Some also accumulates on the surface, to flow off into the sewer after the rain has ended. *The engineer determines the percentage of the rain flowing off in the sewer, by estimating the percentage of maximum run-off of the drainage area.*

The general method for calculating the amount of storm sewage for any particular drainage area, is therefore as follows:

(*a*) Calculate the *time of concentration,* or longest time of flow to the point for which the size of sewer is being determined.

(*b*) Calculate the *rate of maximum rainfall* corresponding to the time of concentration.

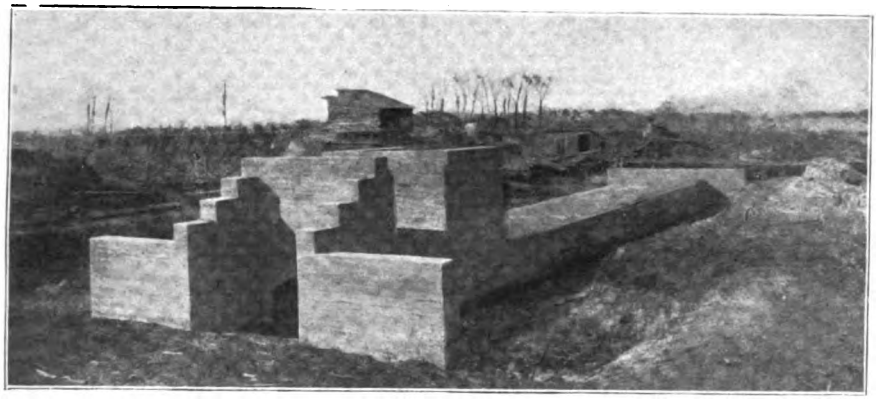
(*c*) Calculate the *percentages of impervious and pervious areas* on the watershed drained by the sewer.

(*d*) Using the percentages of impervious and pervious areas obtained in *c*, calculate the *maximum percentage of run-off,* or the percentage of the rate of the maximum rainfall which will be running off in the sewer under design at the end of the time of concentration.

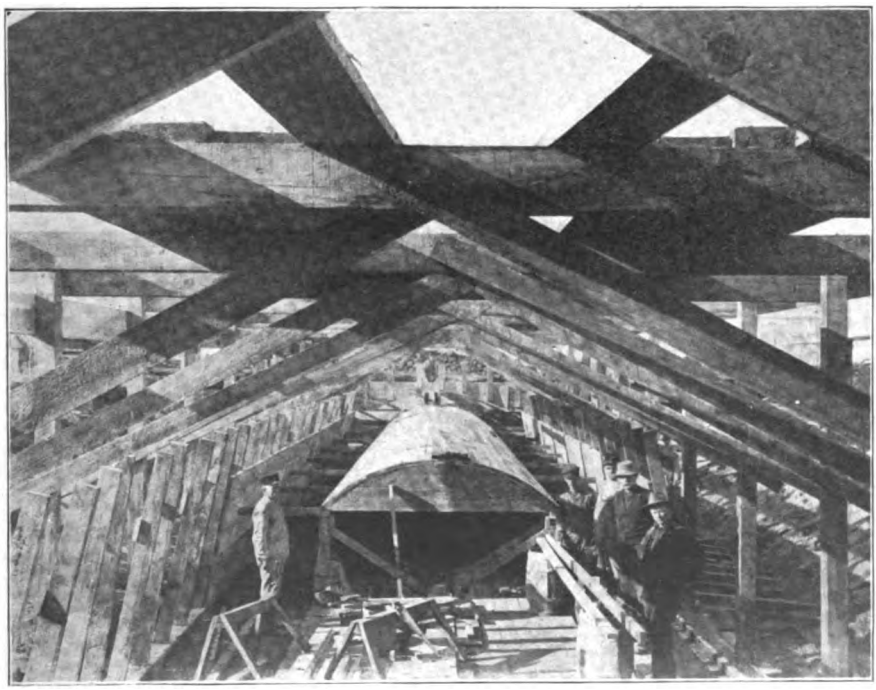
(*e*) *Calculate the total maximum rate of flow of storm sewage,* by *multiplying together* the *drainage area,* the *maximum rate of rainfall* corresponding to the time of concentration, and the *maximum percentage of run-off.*

62. Calculation of the Time of Concentration. The time of concentration, which is the longest time required for water falling on the remote portions of the watershed to flow to the point for which the size of sewer is being determined, will be the sum of, (1), the time required for the water from roofs, yards, sidewalks, and pavements to reach the sewers by way of the gutter and street inlets, and, (2), the longest time required for the water to flow through a line of sewers to the point for which the size of sewer is being calculated.

(1) *Time Required for Water from Roofs, Gutters, etc., to Reach the Sewers.* This will usually be between the limits of 5 and 15 minutes, depending on the steepness of the slopes of the surface and of the gutters, on the distance the water must flow to reach the gutters and the distance it must flow in the gutters to reach the street inlets, on the character of the surface (whether it offers obstructions to flow or not), or whether the roofs are connected to the gutters or directly to

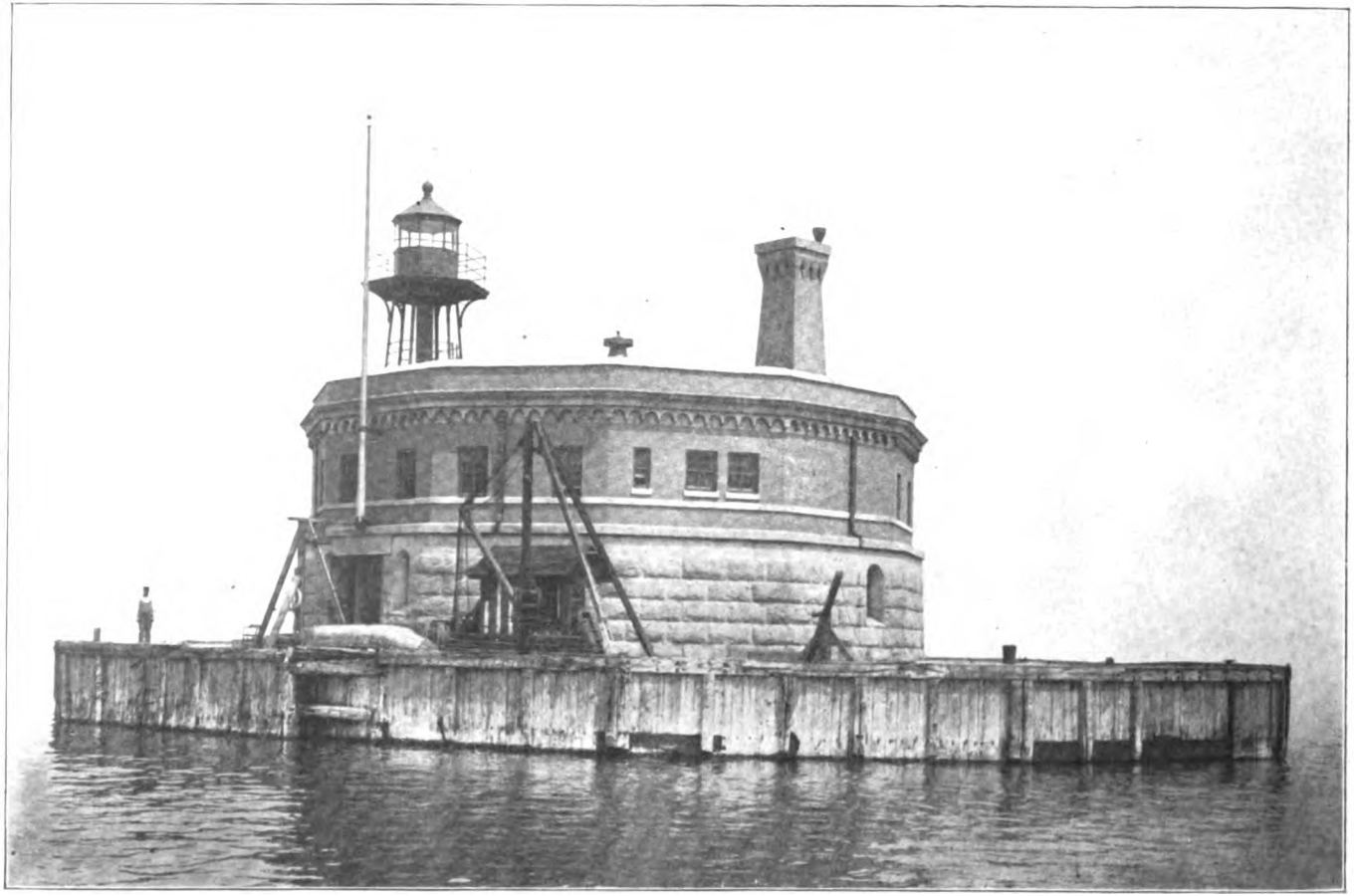


Reinforced-Concrete Arch Culvert, Completed.



Forms for Construction of Arched Culvert Shown Above.

VIEWS OF CONSTRUCTION ON LINE OF ILLINOIS AND MISSISSIPPI CANAL



LAKEVIEW INTAKE CRIB OF THE WATERWORKS SYSTEM OF CHICAGO, ILLINOIS

the sewers, etc. By looking over the ground carefully, and allowing for the above conditions in a general way, the time may be estimated as closely as the data will warrant, without special calculations. The upper limit of 15 minutes may be used when the gutters have a very light grade, and are two blocks long, and where the roofs discharge into the gutters instead of into the sewer direct.

(2) *Longest Time Required for the Water to Flow through the Sewers.* This is computed by taking the grades and sizes of the different parts of usually the longest line of sewers, and determining the corresponding velocities of flow by the use of the sewer diagrams, Figs. 27, 28, and 29, already given. From these velocities, and the lengths of the several portions of the sewer, the corresponding times required for the sewage to flow through each part can be readily computed, and their sum will be the time required. The designing must be begun at the upper ends of the sewers, so that we may know the sizes of sewer needed in computing the times of flow through each portion.

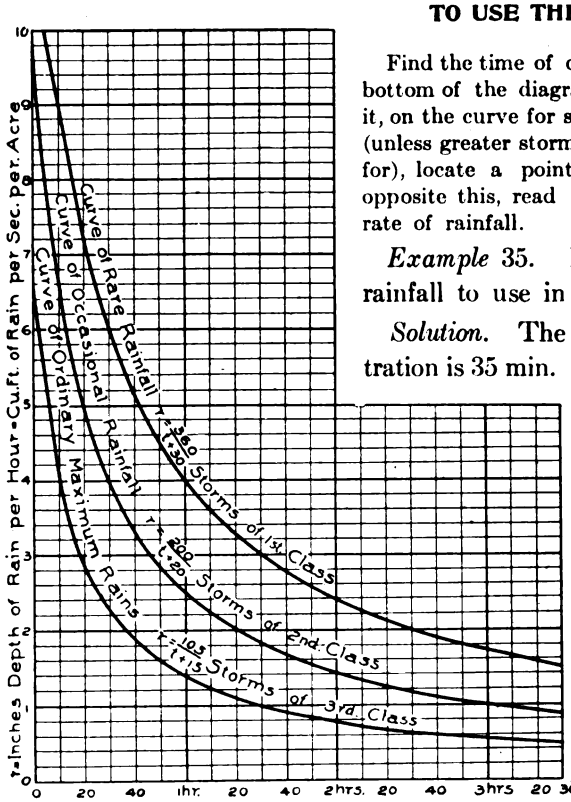
Example 34. Required the time of concentration in the following case: The longest sewer consists of 400 feet of 18-inch pipe sewer, grade 0.5 per cent; 800 ft. of 24-inch pipe, grade 0.3 per cent; 1,200 ft. of 36-inch brick sewer, grade 0.25 per cent; 2,400 ft. of 48-inch brick sewer, grade 0.17 per cent. The roofs discharge into the gutters, through which the sewage must flow 2 blocks at 0.5 per cent grade to reach a street inlet.

Solution:

	Velocity	Time
Estimated for water from roofs and gutter to reach sewer		15.0 min.
In 18-inch sewer, Fig. 27	4.2 ft. per sec.	1.6 "
" 24-inch " " 27	4.0 " " "	3.3 "
" 36-inch " " 28	4.0 " " "	5.0 "
" 48-inch " " 28	4.0 " " "	10.0 "
Answer. Total time of concentration =		35 "

63. Calculation of the Rate of Rainfall Corresponding to the Time of Concentration. In Fig. 34 are reproduced separately the three rainfall curves shown in Fig. 33. Storms of the 1st and 2d classes are rare, and are so very heavy that it would be excessively expensive to build sewers large enough for them. Hence sewers are usually built only large enough to provide for storms of the 3d class.

It is considered less expensive to suffer some damage from rare overcharging of the sewers than to build the greater sizes, though in case very valuable property would be damaged it may be wiser to provide for the heaviest storms.


Curve of Rare Rainfall
Curve of Occasional Rainfall
Curve of Ordinary Maximum Rains
t=30 Storms of 1st Class
t=20 Storms of 2nd Class
t=10 Storms of 3rd Class
r=Inches Depth of Rain per Hour=Cu.Ft. of Rain per Sec. per Acre
0 20 40 1hr. 20 40 2hrs. 20 40 3hrs 20 30

t=Duration of storm in minutes=Time of concentration=Time required for water to flow from the remotest part of the area drained to the point under consideration on the sewer.

Fig. 34. Diagram Showing Rates of Maximum Rainfall to be Used in Calculating the Size of Storm Sewers.

TO USE THE DIAGRAM

Find the time of concentration at the bottom of the diagram. Vertically over it, on the curve for storms of the 3d class (unless greater storms are to be provided for), locate a point; and horizontally opposite this, read off on the left the rate of rainfall.

Example 35. Find the rate of rainfall to use in example 34.

Solution. The time of concentration is 35 min. Over this we read on the curve for 3d-class storms, 2.1 inches per hour.

Answer. 2.1 inches per hour.

64. Calculation of the Percentages of Impervious and Pervious Areas on the Sewer Watershed. The percentage of impervious area may be calculated in the following manner:

Take a typical unit of area, usually one average block, and divide it into different classes of surfaces, having different percentages of imperviousness, as follows:

(*a*) *Roof Area.* From the average size of buildings, and the average number of buildings per block which will be connected with

the sewers or with the gutters, calculate the total roof area in the block. Take this at its full value if the roofs are connected directly with the sewers, but take only 90 per cent if the roofs are connected with the gutters.

(*b*) *First-Class Pavements.* Calculate the total area, per block, of brick, asphalt, stone block, and similar first-class pavements, with tight joints, and take 80 per cent of this area.

(*c*) *Second-Class Pavements.* Calculate the total average area per block, and take 60 per cent.

(*d*) *Third-Class Pavements.* Calculate the total average area per block of good macadam and similar pavements, and take 40 per cent.

(*e*) *Hard-Earth Roads.* Calculate the total average area per block of the traveled, hard-earth surfaces, and take 20 per cent.

(*f*) *Sidewalks.* Calculate the several total average areas per block of 1st, 2d, and 3d-class sidewalks, corresponding to the classes of pavements in *b*, *c*, and *d*, above. If these extend to the gutters, as in business districts, take the same percentages as for the corresponding classes of pavements—namely, 80, 60, and 40 per cent for 1st, 2d, and 3d-class sidewalks, respectively. But if the pavements are separated from the gutters by wide parking, as in the residence districts, take only one-half the above percentages—namely, take 40, 30, and 20 per cent, for 1st, 2d, and 3d-class sidewalks, respectively.

Finally, add together all the reduced average areas per block (*a*, *b*, *c*, *d*, *e*, *and f*) *obtained as above explained, and divide the sum by the total area of the typical block. The quotient will give the percentage of impervious area.*

The percentage of pervious area is obtained by subtracting the percentage of impervious area from 100 *per cent.*

Example 36. In examples 34 and 35, assume the typical block to be 360 ft. square, center to center of streets, as follows:

Streets, 60 ft. wide; pavements, 30 ft. wide; asphalt on two streets; good macadam on the other two; cement sidewalks, 5 ft. wide, on all four streets.

One alley 20 ft. wide.

Lots, 12 in number, each 50 × 140 ft., each lot containing one house, the houses averaging 30 × 40 ft., the roofs connected with the gutter.

Calculate the percentage of impervious and pervious area.

Solution:

(*a*)	Roofs,	$30 \times 40 \times 12 \times .90 =$	12,960 sq. ft.
(*b*)	1st-Class Pavements,	$2 \times 15 \times 360 \times .80 =$	8,640 "
(*d*)	3d-Class Pavements,	$2 \times 15 \times 330 \times .40 =$	3,960 "
(*f*)	1st-Class Sidewalks,	$5 \times 1{,}210 \times .40 =$	2,420 "
	Total impervious area per block		= 27,980 sq. ft.

Total area of one block $= 360 \times 360 = 129{,}600$ sq. ft.

Answer. *Percentage of pervious area* $= \frac{27{,}980}{129{,}600} = 21.58$ per ct.

Percentage of pervious area $= 100 - 21.58 = 78.42$ per cent.

Mr. Emil Kuichling, M. Am. Soc. C. E., has calculated the percentages of impervious area in various cities of New York State, and his work has been repeated by Prof. H. N. Ogden,* who finds the percentage to vary with the intensity of population, as follows:

TABLE VIII

Approximate Percentages of Impervious Area in Cities

Population per Acre	Percentage of Impervious Area	Percentage of Pervious Area
5	4	96
10	9½	90½
15	15	85
20	20½	79½
25	26	74
30	31½	68½
35	37	63
40	42½	57½
45	47½	52½
50	52½	47½
55	58	42

Even very heavily populated sections in the largest cities will seldom have more than 80 to 85 per cent of impervious area.

Table VIII furnishes an easy method of making approximate estimates of the percentages of impervious area.

Example 37. In example 36, estimate the percentage of impervious area by Table VIII.

Solution. The typical block contains 129,600 sq. ft.; and $\frac{129{,}600 \text{ (sq. ft.)}}{43{,}560 \text{ (sq. ft.)}} = 3$ acres. The 12 houses at an average of 5½ persons per house, would give 66 persons per block = 22 per acre.

* *Sewer Design*, p. 62.

Referring to Table VIII we find by interpolating, 22¾ per cent of impervious area, as compared with 21.6 per cent obtained above by the more exact method.

65. Calculation of the Maximum Percentage of Run-Off. Not all of the rain falling on the impervious area of a watershed will run off during the storm. Small amounts are evaporated or absorbed at once, for no city surfaces are absolutely impervious. A larger amount goes to fill up small depressions in the surfaces. A still larger amount accumulates on the surfaces of the watershed, making its way toward the sewer, the amount so accumulated and its rate of movement increasing as the storm continues at the same rate, until finally an equilibrium of flow is established, and the rate of the run-off from the impervious area becomes practically 100 per cent of the rainfall. Thus, the shorter the storm, the less the percentage of run-off from the impervious area; and hence sewer watersheds having the smallest times of concentration are likely to have the smallest percentages of maximum run-off from the impervious areas.

The maximum downpours which determine the size of the sewer, are often preceded by lighter downpours which saturate and partially flood the watershed. Hence *it will probably never be allowable to assume less than 75 per cent as the percentage of maximum run-off from the impervious areas of a sewer watershed, even with very short times of concentration, and comparatively little damage from overcharged sewers.*

With long times of concentration (say 45 minutes or more), and wherever great damage would be caused by overcharged sewers, 100 per cent of maximum run-off from the impervious areas should be assumed.

In the case of long-continued storms, the pervious area becomes gradually saturated, until some run-off occurs from it also. In the case of storms lasting several hours, such as cause the great floods in rivers, this percentage of maximum run-off may be quite high; but for sewers, the times of concentration, and hence the duration of the maximum downpour, are comparatively short—rarely as long as one hour.

For soils of average porosity and for moderate slopes, the percentage of maximum run-off from the pervious areas may be assumed to range from 0, *for* 15 *minutes time of concentration, to, say,* 20 *for* 1

hour's time of concentration. For porous, sandy soils and flat slopes, assume 0 to 50 per cent, and for very impervious soils and very steep slopes, 125 to 150 per cent of the above percentages of maximum run-offs from pervious areas.

Example 38. In examples 36 and 37, assume that the territory is a residence district, with moderate slopes and clay subsoil. Estimate the percentage of maximum run-off.

Solution. Since the time of concentration is only 35 minutes, while the damage from overcharged sewers would not be so great as in a business district, we shall assume 90 per cent maximum rate of run-off from the impervious area. For the pervious area, we interpolate roughly between 0 per cent for 15 minutes, and 17 per cent for 1 hour, and assume 8 per cent maximum rate of run-off.

$.90 \times 21.6$ per cent = 19.4 per cent from impervious area.
$.08 \times 78.4$ " " = 6.3 " " " pervious "

Answer. Total = 26 per cent maximum rate of run-off.

66. Summary of Methods of Computing Sizes of Storm Sewers. We may now summarize the methods of computing the sizes of storm sewers, described above in Articles 61 to 65, inclusive, as follows:

(*a*) Calculate the *time of concentration* (Art. 62), or longest time of flow from the remote portions of the sewer watershed to the point for which the size of sewer is being calculated.

(*b*) Calculate the *maximum rate of rainfall* (Art. 63) corresponding to the time of concentration.

(*c*) Calculate the *percentages of impervious and pervious areas* on the sewer watershed (Art. 64).

(*d*) From the percentages of impervious and pervious areas, and knowledge of the characteristics of the sewer watershed, calculate the *percentage of maximum run-off* (Art. 65).

(*e*) Calculate the *maximum rate of flow of storm sewage*, by *multiplying together* the *area of the sewer watershed in acres*, the *maximum rate of rainfall in inches per hour* (*b*), and the *percentage of maximum run-off* (*d*). The product will be the *cubic feet per second of maximum storm sewage flow.*

(*f*) Knowing the grade of the sewer, refer to Fig. 27, or Fig. 28, or Fig. 29, according to the shape and material of the sewer, and determine the size of sewer required to carry the maximum flow of storm sewage (*e*) when flowing full.

Example 39. In examples 34 to 38, assume that the sewer watershed is 5,280 feet long by 800 feet wide, and that the grade of the circular brick outlet sewer is to be 0.15 per cent. Calculate the required diameter.

(*a*) The time of concentration = 35 min. (see Ex. 34).

(*b*) The rate of maximum rainfall = 2.1 in. per hr. (see Ex. 35).

(*d*) The percentage of maximum run-off = 26 (see Ex. 38).

(*e*) The drainage area $= \frac{5{,}280 \times 800}{43{,}560} = 97$ acres.

$$97 \times 2.1 \times .26 = 53 \text{ cu. ft. per sec.}$$

= maximum flow of storm sewage.

(*f*) Referring to Fig. 28, we find, by interpolating between the 4-foot and 5-foot diameters, that for a grade of 0.15 per cent a diameter of 4 ft. 3 in. will be required for a circular brick sewer which can carry 53 cu. ft. per sec.

Answer. A 4 ft. 3 in. circular brick sewer.

GENERAL EXAMPLE FOR PRACTICE

67. Before proceeding further, the student should work out the following example in computation of the proper size of sewer:

Example 40. A thickly built-up sewer district, having a population of 35 persons per acre, contains 160 acres. The slopes are very flat, and the soil is sandy and porous. The longest line of sewers is 6,000 feet; and the velocity of flow in the sewers averages four feet per second. The roofs are connected with the gutters, in which the longest flow is two blocks. Calculate the diameter of the circular, brick outlet sewer, laid to a 0.08 per cent grade (NOTE: Use Table VIII.)

Answer. A 6-foot circular brick sewer.

TRENCH MACHINE IN OPERATION ON GORHAM AVENUE, BROOKLINE, MASSACHUSETTS

Metropolitan Water and Sewerage System of Boston.

SEWERS AND DRAINS

PART II

LAND DRAINS AND SUBDRAINS

68. General Discussion of Land Drains. Definitions of sewers and drains were given in Art. 1. Land drains have for their object the reclaiming of wet lands, to render them suitable for cultivation. The reclamation of wet lands also greatly improves the sanitary condition of the vicinity.

There are two principal kinds of land drains—namely, *tile drains*, or lines of agricultural drain tiles laid a few feet beneath the surface of the ground, to remove ground water; and *drainage ditches*, or open channels, made to serve as outlets for the tile drains and to drain ponds and remove surface water.

69. Planning and Construction of Land-Drainage Systems. When a tile drainage system is projected, a competent drainage engineer should at once be engaged to do the necessary surveying, plan the system, and pass on the construction.

The surveying will include the obtaining of data for a complete map of the system; and each drain should be staked out, stakes being set 50 feet apart, and an elevation taken with a good level at each stake. All the work should be checked.

The engineer should then prepare for the landowner a complete map of the system, to a scale of 200 to 400 feet per inch; also a sheet of profiles, including a profile of each drain, showing the depth and grade at all points. Without such map and profiles, knowledge of the system may be lost, and, on some future occasion, when very badly needed, may be unavailable.

The engineer should plan as simple and regular a tile system as possible, adopting long, parallel, straight lines of tile when practicable, with as few junctions as possible.

The grades may be very light in case of necessity, and short tile drains have worked well even at level grades; but the lighter the grade, the greater should be the care used in construction.

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The minimum depths should usually be 3½ to 4 feet. Shallower depths do not drain out the soil so thoroughly; and tile, if laid 3½ to 4 feet deep, can be placed farther enough apart to more than make up for the cost of the greater depth.

The lines of tile should usually be placed from five to ten rods apart, depending on the soil—farthest apart in the most porous soil. The outlet should be built with special care; and a masonry wall should be constructed to hold the last length of tile.

For drainage ditches, careful surveys of the entire watershed must be made by a very competent engineer; and fully detailed plans and specifications must be prepared.

70. Contracts and Specifications for Tile Drains. The employer and the tile ditcher should sign a printed contract with detailed specifications, such as given herewith:

CONTRACT

It is hereby agreed between ....., employer, and....., contractor, that the contractor shall, except for the furnishing of the tile along the ditch and the refilling of the ditch, entirely construct for the employer the following described drains:

.....
.....
.....
.....
.....
.....

It is further agreed that for the above work the employer shall pay the following prices:

.....
.....
.....

It is further agreed that the employer.....
.....furnish board free to the contractor and his helpers during active prosecution of the work.

It is further agreed that the contractor shall begin the work by.....
.....and complete the same by.....

It is further agreed that all the above work and the payments therefor shall be in strict accordance with the specifications given below and with the engineer's maps, profiles, and plans, all of which are hereby made a part of this contract.

Witness the hands of the respective parties, this.....day of
.....A. D.....

.....Employer
.....Contractor

SPECIFICATIONS

1. *Staking Out the Work.* The work will be staked out by the engineer, and his stakes must be carefully preserved and followed.

2. *Digging the Ditches.* The digging of each ditch must begin at its outlet, or at its junction with another tile drain, and proceed toward its upper end. The ditch must be dug along one side of the line of survey stakes, and about ten inches distant from it, in a straight and neat manner, and the top soil thrown on one side of the ditch and the clay on the other. When a change in the direction of ditch is made, it must be kept near enough to the stakes so that they can be used in grading the bottom. In taking out the last draft, the blade of the spade must not go deeper than the proposed grade line or bed upon which the tiles rest.

3. *Grading the Bottom.* The ditch must be dug accurately and truly to grade at the depths indicated by the figures given by the engineer, measured from the grade stakes. At each grade stake, a firm support shall be erected; and on these supports a fine, stout cord shall be tightly stretched over the center line of the ditch and made parallel with the grade by careful measurements at each stake, using a carpenter's level. Supports shall be kept erected at at least three grade stakes, and the work checked each time by sighting over them. Intermediate supports shall be set and lined in by careful sighting wherever necessary, to support the cord every 50 feet. A suitable measuring stick shall be passed along the entire ditch, and the bottom in all parts made true to grade by measuring from the cord. The bottom must be dressed with the tile hoe, or, in the case of large tiles, with the shovel, so that a groove will be made to receive the tile, in which the tile will remain securely in place when laid.

4. *Laying the Tile.* The laying of the tile must begin at the lower end and proceed upstream. The tile must be laid as closely as practicable, and in lines free from irregular crooks, the pieces being turned about until the upper edge closes, unless there is sand or fine silt which is likely to run into the tile, in which case the lower edge must be laid close, and the upper side covered with clay or other suitable material. When in making turns, or by reason of irregular-shaped tile, a crack of one-fourth inch or more is necessarily left, it must be securely covered with broken pieces of tile. Junctions with branch lines must be carefully and securely made.

5. *Blinding the Tile.* After the tile have been laid and inspected by the employer or his representative, they must be covered with clay to a depth of six inches, unless, in the judgment of the employer or his representative, the tile are sufficiently firm so that complete filling of the ditch may be made directly upon the tile. In no case must the tile be covered with sand without other material being first used.

6. *Risk During Construction.* The ditch contractor must assume all risks from storms and caving-in of ditches; and when each drain is completed, it must be free from sand and mud before it will be received and paid for in full. In case it is found impracticable, by reason of bad weather or unlooked-for trouble in digging the ditch or properly laying the tile, to complete the work at the time specified in the contract, the time may be extended as may be mutually agreed upon by the employer and contractor. The contractor shall use all necessary precaution to secure his work from injury while he is constructing the drain.

7. *The Tile to be Used.* Tile will be delivered on the ground convenient for the use of the contractor. No tile shall be laid which are broken, or soft, or so badly out of shape that they cannot be well laid and make a good, satisfactory drain.

8. *Prosecution of the Work.* The work must be pushed as fast as will be consistent with economy and good workmanship, and must not be left by the contractor for the purpose of working upon other contracts, except by permission and consent of the employer. All survey stakes shall be preserved, and every means taken to do the work in a first-class manner.

9. *Subletting Work.* The contractor shall not sublet any part of the work in such a way that he will not remain personally responsible, nor shall any other party be recognized in the payment for work.

10. *Plant and Tools.* The contractor shall furnish all tools which are necessary to be used in digging the ditches, grading the bottom, and laying the tile. In case it is necessary to use curbing for the ditches, or outside material for covering the tile where sand or slush is encountered, the employer shall furnish the same upon the ground convenient for use.

11. *Payments for Work.* Every.....weeks during the prosecution of the work, the contractor may claim and the employer shall pay 75% of the value of the work completed satisfactorily, the engineer being the arbiter in case of dispute as to the amount of work satisfactorily completed. The remaining 25% will be retained until the entire work is completed satisfactorily, as certified by the engineer after a final inspection, at which time the whole amount due shall be paid. Prior to any payment, the employer may require a correct statement of all claims incurred by the contractor for labor, materials, or damages on account of the work; and the employer may withhold payments until proof has been presented by the contractor of release of all liens against the employer on account of such claims.

12. *Duties of Engineer.* The engineer shall have authority to lay out and direct the work, and to inspect and supervise the same during construction and on completion, to see that it is properly done in accordance with the contract. His instructions should be fully carried out.

13. *Failure to Comply with Specifications.* In case the contractor shall fail to comply with the specifications, or refuse to correct faults in the work as soon as they are pointed out by the engineer or other person in charge, the employer may declare the contract void; and the contractor, upon receiving seventy-five per cent of the value of the completed drains at the price agreed upon, shall release the work and the employer may let it to other parties.

71. Benefits of Tile Drains. The advantages of tile drains may be enumerated as follows:

1. Tile drainage, by making the soil firm, enables earlier cultivation in the spring. Low ground drained can be cultivated earlier than high ground not drained.

2. Careful observations have shown that tile drainage makes the soil several degrees warmer in the spring. Scientific tests have

shown this increased warmth to be of the utmost importance in promoting the germination and growth of crops.

3. Tile drainage promotes pulverization of the soil, putting it in good condition to cultivate, and preventing baking and the formation of clods.

4. Tile drainage removes from the pores of the soil surplus and stagnant water, which would drown and destroy the roots of plants.

5. Tile drainage makes certain the proper "breathing" of the soil, or free circulation of air in its pores, which is essential to healthy plant growth.

6. Tile drainage establishes in the soil the proper conditions required for the satisfactory carrying on of the chemical processes necessary to prepare the plant food for its use by vegetation.

7. Tile drainage fits the soil for the vigorous life and action of the soil bacteria which are essential to preserve and increase its fertility and promote the growth of crops.

8. Tile drainage increases the depth of soil which can be reached by the roots of plants and drawn upon for plant food.

9. Because in them the roots of plants can penetrate deeper, where they are protected from heat and drouth and can reach the deep-seated moisture, tile-drained soils stand drouth better than undrained soils.

10. By putting the top 3-feet or 4-feet layer of soil into a porous condition, tile drainage enables soils to absorb rain water instead of discharging it over the surface, and so helps to prevent surface wash and consequent loss of fertility.

11. By causing this porous condition, tile drainage makes the upper 3 or 4 feet of soil into an enormous reservoir to catch the rain water and discharge it only slowly into the streams. Thus tile drainage prevents floods instead of causing them.

12. Tile drainage does away with irregular shaped fields, cut up by sloughs and ditches, and so cheapens cultivation.

Benefits of Large Ditches. Tile drainage is always preferred to open-ditch drainage if the drain is not too large. The advantages of large ditches may be enumerated as follows:

1. By furnishing channels to remove storm water, they prevent, if of ample size, the inundation of low-lying lands by floods and surface water.

2. They have a minor value for draining off the ground water from a narrow strip of land each side.

3. One of their main values is in furnishing outlets for tile drains, and in many places tile drainage is impracticable till outlet drainage ditches have been built.

72. Method of Computing Sizes of Tile Drains. The drained soil above the level of tile drains contains a large percentage of air-space in the pores between the soil particles; and this layer of porous soil acts like a great sponge several feet thick to absorb the rain as it falls. Hence the water reaches the tiles very slowly. It has been found that under average conditions tiles will not be called upon to carry more than ¼-inch depth of water in 24 hours. This equals 6,800 gallons per acre per day, or 4,352,000 gallons per square mile per day. The sizes of tile drains for average conditions may readily be taken from Table IX.

TABLE IX

Number of Acres Drained by Tiles Removing ¼-inch Depth of Water in 24 Hours

Grades		Diameters of Tile Drains										
Per cent	Inches per rod	3 in.	4 in.	6 in.	8 in.	10 in.	12 in.	15 in.	18 in.	20 in.	22 in.	24 in.
0.03	1/16					37	59	109	159	205	254	319
0.05	3/16		5	13	28	49	75	131	219	264	332	411
0.10	2/16	4	7	19	40	69	109	186	289	373	471	582
0.15	3/16	4	9	24	49	85	132	232	355	458	577	713
0.25	5/16	5	10	28	56	97	153	264	410	529	667	823
0.30	6/16	6	12	33	69	119	188	322	502	648	808	1,008
0.40	8/16	7	14	39	79	138	216	371	580	748	942	1,165
0.50	1	8	16	44	89	154	246	416	648	838	1,050	1,300
0.60	1 3/16	9	17	48	97	169	266	457	710	911	1,154	1,422
0.70	1 5/16	10	19	50	105	182	287	488	768	988	1,242	1,549
0.80	1 6/16	10	20	55	114	195	307	526	822	1,059	1,332	1,645
0.90	1¾	10	21	59	119	207	326	558	872	1,123	1,414	1,747
1.00	2	11	22	62	126	218	343	589	917	1,176	1,495	1,838
1.50	3	13	28	75	153	267	419	722	1,123	1,450	1,824	2,256
2.00	4	15	31	88	178	309	485	832	1,297	1,676	2,110	2,594
3.00	5 5/16	19	39	107	216	377	593	1,020	1,589	1,957	2,592	
4.00	7 5/16	22	45	123	253	437	683	1,176				
5.00	9⅞	25	50	138	280	486	765					
7.50	14⅞	30	61	169	344							
10.00	19 5/16	35	71	195								

Table IX is computed from the form of Poncelet's formula recommended for use with tile drains by C. G. Elliott, drainage expert to the U. S. Agricultural Department, Washington, D. C., who recommends the above sizes to drain

ground water only. If surface water is also to be removed, as in the case of ponds without other outlets, the tiles will drain safely only one-half to one-third the number of acres given in the table.

When part of the land in the watershed is rolling, not requiring tiling, count only one-fifth to one-third of such rolling land, in addition to all of the low, flat land, in getting the size of tiles to remove ground water only.

Example 41. What size of tile laid to a 0.1 per cent grade will carry the under-drainage of 160 acres of flat land?

Answer. 15 inches.

Example 42. What size of tile to a 0.2 per cent grade will carry the under drainage of 240 acres, two-thirds rolling?

Answer. 80 acres flat land, *plus* one-third of 160 acres rolling, gives 133⅓ acres, requiring a 12-inch tile.

Example 43. What size of tile laid to 0.3 per cent grade will be required to remove both ground and surface water from a pond whose watershed includes 40 acres?

Answer. 10-inch. (NOTE.—Double or triple the area for both ground and surface water.)

73. Method of Computing Sizes of Drainage Ditches. Since drainage ditches must carry surface water as well as ground water, their capacities must be larger than those of tile drains for the same number of acres drained. It has been found by experience that they must carry from ¾-inch depth for small drainage areas, to ½-inch depth for large drainage areas per day. Their size can be taken from Table X.

Example 44. What width of ditch, having a fall of 5 feet per mile, and a depth of water of 3 feet, will be required to drain an area of 5 square miles (3,200 acres)?

Answer. About 12 feet.

Example 45. What size ditch having a fall of 3 ft. per mile, and 9 ft. depth of water, will drain an area of three townships (69,120 acres)?

Answer. About 22 feet.

74. Method of Computing Sizes of Subdrains for Sewers. Sewer subdrains act like tile land drains to remove the ground water from the soil. Being deeper, they will drain wider strips of land—say averaging 16 rods wide, instead of 8 rods, for ordinary land drains in average soil; but also, owing to the greater depth, the water will reach the tiles more slowly, and this may offset the greater width drained. We may assume roughly that each subdrain may be called upon to remove ⅛-inch depth of water per day from a strip 16 rods wide, *which is the same thing as ¼-inch depth per day from a strip of land 8 rods wide.*

TABLE X

Number of Acres Drained by Open Ditches

Depth of Water, 3 feet.						*Depth of Ditch, at least 4 feet.*				*Depth of Water, 5 feet.*				*Depth of Ditch, at least 6.5 feet.*		
Grade		Average Width of Water								Average Width of Water						
Per cent	Feet per Mile	4 feet	6 feet	8 feet	10 feet	15 feet	20 feet	30 feet	50 feet	6 feet	8 feet	10 feet	15 feet	20 feet	30 feet	50 feet
0.02	1.0			725	970	1,570	2,240	5,300	18,400	980	1,470	1,900	5,000	7,150	23,800	43,800
0.04	2.1	400	690	1,000	1,360	2,250	4,700	7,470	26,100	1,390	2,090	2,800	7,200	20,400	33,500	62,500
0.06	3.2	492	850	1,260	1,690	2,770	5,770	18,400	31,900	1,710	2,560	5,100	17,600	24,700	40,800	75,500
0.08	4.2	572	980	1,460	1,950	4,820	6,670	21,400	37,400	1,980	2,980	6,100	20,400	30,000	48,800	88,000
0.10	5.3	636	1,100	1,630	2,180	5,360	7,440	23,700	41,400	2,220	5,010	7,600	23,400	33,400	54,500	98,000
0.15	7.8	791	1,330	2,010	2,670	6,600	19,000	30,200	52,100	2,720	6,300	17,100	28,700	40,500	66,700	120,000
0.20	10.6	905	1,560	2,310	4,720	7,870	21,800	35,000	60,300	4,820	7,300	19,500	33,000	47,000	77,000	139,000
0.25	13.2	1,020	1,740	2,660	5,300	17,500	24,600	39,000	67,700	5,370	16,300	21,900	37,500	53,000	86,000	155,000
0.30	15.8	1,100	1,970	2,900	5,850	19,400	26,800	42,700	74,000	5,900	17,900	23,900	40,700	57,000	94,000	170,000
0.40	21.1	1,300	2,290	5,050	6,740	22,200	30,800	49,400	85,700	6,830	20,600	27,700	47,000	67,000		
0.50	26.4	1,475	2,550	5,620	7,500	24,800	34,800	55,300	95,200	7,600	23,000	31,000				
0.60	31.7	1,600	2,790	6,230	16,500	27,200	37,700	60,400		16,700	25,200	33,900				
0.70	37.0	1,720	3,010	6,650	17,800	29,400	41,200			18,100	27,300					
0.80	42.2	1,850	4,850	7,170	19,100					19,000						
0.90	47.5	1,955	5,140	7,550	20,100					20,500						
1.00	52.8		5,400													

TABLE X—(Concluded)

Number of Acres Drained by Open Ditches

Depth of Water, 7 feet.		*Depth of Ditch, at least 9 feet.*						*Depth of Water, 9 feet.*	*Depth of Ditch, at least 11.5 feet.*			
Grade		Average Width of Water						Average Width of Water				
Per cent	Feet per mile	8 feet	10 feet	15 feet	20 feet	30 feet	50 feet	10 feet	15 feet	20 feet	30 feet	50 feet
0.02	1.0	2,300	4,700	16,600	28,000	48,000	88,500	6,550	27,800	40,800	69,500	127,000
0.04	2.1	4,850	6,740	23,400	35,400	58,000	106,000	18,500	34,400	50,000	83,500	157,000
0.06	3.2	5,920	17,000	29,600	43,400	72,000	129,000	22,600	41,600	61,000	103,000	193,000
0.08	4.2	6,940	19,100	34,200	50,000	83,000	150,000	26,300	48,300	71,000	120,000	221,000
0.10	5.3	7,720	21,800	38,400	56,000	92,600	167,000	30,400	54,000	79,100	132,000	244,000
0.15	7.8	19,400	27,000	47,200	68,500	112,000	202,000	37,300	66,100	96,200	162,000	298,000
0.20	10.6	22,400	31,300	54,200	78,700	130,000	235,000	42,900	76,200	104,000		
0.25	13.2	25,000	34,800	60,500	88,000	146,000		48,000	85,300	125,000		
0.30	15.8	27,400	38,200	66,200	96,500			52,500	93,200			
0.40	21.1	31,700	44,100					60,800				
0.50	26.4	35,400										

Table X, for open ditches, is calculated by the well-known standard Kutter's formula, using a "coefficient of roughness" equal to 0.030. This coefficient of roughness is the value recommended by Kutter for channels in moderately good condition, having stones and weeds occasionally, and agrees with actual gaugings of drainage channels made at the Iowa State College. For ditches in first-class condition, the number of acres given may be increased about 25 per cent. The table has been calculated for ditches having sides with slopes of one foot horizontal to one foot vertical but is approximately correct for other slopes.

The capacity of the ditches has been made as recommended by C. G. Elliott, U. S. Agricultural Department drainage expert, as follows, the ditches to run not more than $\frac{8}{10}$ full for the capacities mentioned:

Above the upper heavy line, ¾-inch depth of water per 24 hours

Between the two heavy lines, ½-inch depth of water per 24 hours.

Below the lower heavy line, ¼-inch depth of water per 24 hours.

Local conditions may vary the size needed, and it is necessary to consult a drainage engineer in each case.

Hence the sizes required for sewer sub-drains may be taken from Table IX, calculating the number of acres drained by multiplying the total lengths of tributary drain tile, in feet, by 132 *feet* (= 8 *rods*), *and dividing the product by* 43,560 *sq. ft.*

The above method will give a capacity approximating 110,000 gallons per day per mile of tributary subdrains. As sewers are ordinarily distributed, it will give a capacity approximating 1,500,000 gallons per day per square mile of territory served by the sewers.

Example 46. Calculate the size of subdrains laid to a 0.25 per cent grade, required to serve as outlet for 30,000 linear feet of tributary subdrains.

Solution: $\frac{30{,}000 \times 132}{43{,}560} = 91$ acres = equivalent area drained for $\frac{1}{4}$-inch depth.

In Table IX, opposite the 0.25 per cent grade, we find that a 10-inch tile would be required.

Answer. 10-inch tile subdrain.

75. Cost of Tile Land Drains and Drainage Ditches. The cost of tile-drain construction in central Iowa in 1904, can be approximated from Table XI. Local prices should be determined before using the table for close estimates of work done elsewhere.

TABLE XI
Cost of Tile Drains

Size of Tile	Price per 1,000 Feet	Weight per Foot	Cost of Hauling 1,000 Feet 5 Miles	Cost of Digging and Laying, per Rod			Refilling, per Rod
				3 feet deep or less	Add per foot for additional depth over 3 feet		
					3–6 ft.	over 6 ft.	
3 in.	$ 16.00	5	$ 3.12	$ 0.35	$ 0.15	$ 0.30	2c.-5c.
4 in.	22.00	8	5.00	0.35	0.15	0.30	2c.-5c
5 in.	30.00	10	6.25	0.35	0.15	0.30	2c.-5c.
6 in.	40.00	12	7.50	0.35	0.15	0.30	2c.-5c.
7 in.	50.00	15	9.37	0.35	0.20	0.35	2c.-5c.
8 in.	60.00	20	12.50	0.40	0.20	0.35	2c.-5c.
10 in.	95.00	30	18.75	0.45	0.20	0.35	2c.-5c.
12 in.	120.00	40	25.00	0.50	0.20	0.35	2c.-5c.
15 in.	250.00	50	31.25				
18 in.	400.00	80	50.00				
20 in.	600.00	100	62.50				
24 in.	800.00	125	78.12				

The cost of hauling given in Table XI is on the basis of $1.25 per ton, or $2.50 per day for a man and team, making two trips.

The prices for digging and laying given above include board furnished by the ditcher. If the farmer furnishes board, deduct about 20 per cent. The prices for digging and laying are for average ground, and should be increased for quicksand or very wet soils.

N. B. To all estimates it is wise to add 5 per cent to 10 per cent for contingencies and engineering.

Example 47. What will be the cost of 2,000 feet of 6-in. tile drain, 2½ miles from the tile yard, of which 1,000 feet is 4 feet deep, 500 feet 5 feet deep, and 500 feet 6 feet deep, in average soil?

Answer:

2,000 ft. of 6 in. tile @ $40.00	$80
Hauling 2,000 ft. 2½ miles, @ $3.75	7½
Digging and laying 60.6 rods 4 ft. deep, @ 50c	30½
" " " 30.3 rods 5 ft. deep, @ 65c	19½
" " " 30.3 rods 6 ft. deep, @ 80c	24
Refilling 121.2 rods (by team), @ 2c	2½
	$164
Add 10 per cent for engineering, etc.	16
Estimated cost	$180

Cost of Open Drainage Ditches. The cost of open drainage ditches is estimated by the cubic yard.

To calculate the number of cubic yards per foot of length of ditch, multiply the average width by the average depth, and divide by 27. Thus a 7-ft. by 12-ft. ditch contains $\frac{7 \times 12}{27} = 3\frac{1}{9}$ cubic yds. per foot length.

The cost per cubic yard in Iowa varies from 7c. to 18c., depending on the size of the job, the character of the soil, and other local conditions, including the certainty of the contractor getting his money promptly. The larger the work, the less is the cost per cubic yard.

HOUSE SEWERAGE

76. Definitions and General Description. A *house sewer* is a small branch sewer which connects the house with the street sewer. In Fig. 6 a general view of a house sewer is given.

A *soil pipe* is the main drainage pipe of the system of house plumbing, into which the different fixtures discharge. See Fig. 35.

A *trap* is a bend or depression in a pipe or drain, which remains constantly full of liquid, thus shutting off air-connection between the portions of the pipe or drain on opposite sides of the trap. See Fig. 35.

A general idea of an entire system of house sewerage can be obtained from Figs. 6 and 35, which see.

The house sewer and outlet for the cellar and foundation drains, extend from the street sewer to the house as shown in Fig. 6.

The iron soil pipe should begin a few feet outside the house, and extend full size through the roof, the separate fixtures discharging into the soil pipe, each protected by a trap, and all traps being vented, as shown in Fig. 35. The dotted lines in Fig. 35 show alternative plans sometimes adopted for house sewerage.

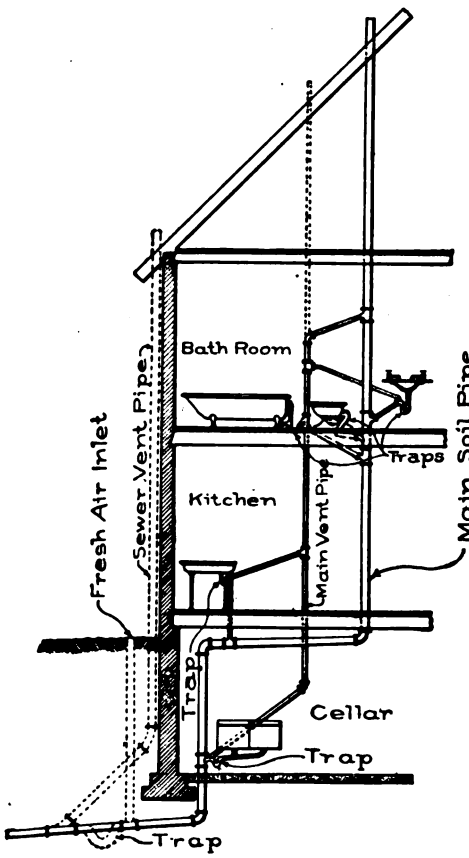


Fig. 35. Diagram of House Sewerage System.

77. House Sewers. House sewers (see Fig. 6) are usually made of vitrified sewer pipe the same as street sewers, and should be constructed with fully as much care. The joints should have gaskets of hemp or oakum, and be carefully cemented, the same as street sewers. (See Art. 33.)

Each piece of pipe should be laid to the exact grade by measuring from a grade string, the same as for street sewers (see Art. 98). The grade should usually be not less than 2 per cent. The house sewer should, if possible, be perfectly straight, both in alignment and in grade, from the house to the house connection at the sewer.

Inspection pipes should be placed just inside the lot line, as indicated in Fig. 6.

House sewers should usually be 4-inch circular pipe. If too large, they are more difficult to keep flushed clean, and they may carry to the street sewer things large enough to cause stoppages, improperly put into the house fixtures. Sometimes 5-inch or 6-inch house sewers are used.

78. General Principles of House Plumbing. The following general principles should be carefully observed in the installation of all house plumbing:

1. The iron pipe should begin a few feet outside the house, as vitrified pipe does not have tight joints and is liable to be broken, where it passes through the foundation wall, by uneven settlement.

2. No pipes carrying sewage should be allowed to be buried under the basement floor, unless placed in masonry-lined trenches with removable covers.

3. All pipes of the plumbing system should be iron or lead, with absolutely tight joints of lead, or screwed, or soldered.

4. In general, no pipes should be built into partitions or walls, where they cannot be gotten at, unless removable panels are placed over them.

5. All fixtures should be completely exposed to view, and should not be enclosed in woodwork. Sinks and washbowls, for example, should be supported on brackets or legs, with clear, open spaces under them.

6. All fixtures should be of durable, smooth, and non-absorbent material, such as porcelain or enameled iron. The least possible woodwork should be used.

7. All fixtures should be located in well-lighted and well-ventilated places.

8. Each fixture must be protected by a good trap. There must be no openings from the plumbing system into the interior of the house not thoroughly protected by traps sure to stay full of liquid.

9. Thorough ventilation of all pipes must be provided for.

10. All pipes must be laid to good grades, without sags, so as to drain completely and quickly.

11. The cellar and foundation drains should be connected with a sewer subdrain, if possible, and not with a sewer, owing to the danger of the water in the traps evaporating in dry weather when no water runs in the drains. If absolutely necessary to connect to the sewer, excessively deep traps should be used, to lessen the danger of evaporation.

79. Soil Pipes. The iron soil pipe begins, as already stated, a few feet outside the foundation wall. At this point a *disconnecting trap* is sometimes placed, as shown by the dotted lines in Fig. 35, in which case a *fresh-air inlet* must be placed on the house side of the

trap, as also shown by dotted lines in Fig. 35, to permit complete ventilation of the soil pipe.

The soil pipe should extend full-sized and without any obstruction, a few feet above the roof. It should everywhere be readily accessible, and will naturally be placed in the location most convenient for attaching the fixtures.

The soil pipe is usually 4 inches in diameter, made of cast iron, with air-tight, leaded and calked joints.

80. Traps. The best traps are simply *smooth bends* in the plumbing pipes, giving depressions which stand full of liquid. If the curves are not smooth, or if there are sudden changes in size, the danger of stoppage is increased. The depth from the highest level of the water in the trap to the top of the liquid in the lowest portion, is called the *seal* of the trap. Traps are necessary evils in plumbing systems, as they tend to cause stoppages.

The seals of traps may be forced by any compression or rarefaction of air in the plumbing pipes, such as may be caused by *plugs* of sewage from other fixtures descending the pipes, unless a *vent pipe* is extended from the *crown* or highest point of each trap on the side next to the soil pipe, as shown in Fig. 35.

Traps should be located as closely as possible to the fixtures they are to protect.

81. Ventilation. The vent pipes from the traps mentioned in Art. 80, above, and shown in Fig. 35, serve also to secure ventilation of branch pipes. They should unite in a *main vent pipe*, 2 inches in diameter, as shown in Fig. 35, and this may turn into the soil pipe above the highest fixture, or may extend independently above the roof, as shown by the dotted lines in Fig. 35.

The extension of the main soil pipe unobstructed through the roof, with admission of air from the sewer (or through the fresh-air inlet if a disconnecting trap is used), together with the trap vent pipes and the main vent pipe, as shown in Fig. 35, insure ventilation of all parts of the plumbing system.

COST OF SEWERS, AND METHODS OF PAYING FOR THEM

82. Preliminary Estimates of Cost of Sewers. One of the first things which the sewerage engineer will be asked about sewers for

which he has made plans, is what will be their cost. He must be able to answer this question readily, and with close approximation to the actual cost.

Many factors affect the cost of sewers, some of which cannot be exactly foretold. Among the things which can be closely ascertained in advance, are the sizes, lengths, and depths of the sewer, and the amounts of the various kinds of materials required. Among the things which cannot be exactly foretold, are the nature of the soil, the amount of ground water to be encountered, the weather conditions, and the labor conditions.

The competent engineer will thoroughly study all conditions which may affect the cost, before preparing his estimates, and even then will allow a liberal percentage for contingencies.

The engineer should have borings made to determine the character of the soil and the level of ground water, and should learn all he can of previous experience in the town with ditches and other excavations. Even then the actual soil often proves very different from what was anticipated.

After making the preliminary study and plans, the engineer tabulates the sewers by lengths, depths, sizes, and character, together with the manholes, lampholes, flush-tanks, and other items of the system. He then assigns a unit price to each item, after careful study of all conditions, and calculates the total cost.

The data of cost which follow are for average conditions only, and only for the localities named. They will need to be modified by the engineer to meet different conditions.

83. Cost of Pipe Sewers. In estimates of the cost of pipe sewers, the work is usually divided into the following items:

(1) *Trenching and Refilling.* This includes excavating the trench for the sewer, refilling it, and compacting the material after the sewer pipe is laid. Trenching and refilling are usually itemized according to depth, thus:

Trenching and Refilling under 6 feet depth
" " " " 6 to 8 feet depth
" " " " 8 to 10 feet depth
Etc., etc.

The cost of trenching and refilling will vary somewhat also with the diameter of the sewer; but this is often not separately itemized.

For estimates and bids, the lengths in linear feet of each depth of sewer are taken from the profiles, and listed in the tabulation.

(2) *Furnishing Sewer Pipe and Specials.* The pipe are usually specified to be delivered on board cars at the town where they are to be used. The amounts are usually itemized according to the diameters, thus:

Furnishing sewer pipe 8 inches diameter
" " " 10 " "
" " " 12 " "
etc., etc.

Specials are sometimes itemized separately, and sometimes included in the prices for furnishing pipe, the average distance apart being specified.

For estimates and bids, the total lengths of each size of pipe are ascertained and listed in the tabulation.

(3) *Hauling and Laying Sewer Pipe and Specials.* This includes taking the sewer pipe from the cars, hauling them to the sewer, furnishing cement, sand, and hemp or oakum, and laying the pipe according to the specifications. Some labor in excavating bell holes and a few inches at the bottom of the ditch shaped to fit closely the under side of the pipe, is also included. Hauling and laying are usually itemized according to the diameters of the pipe, thus:

Hauling and Laying sewer pipe and specials, 8 inches diameter
" " " " " " " 10 " "
" " " " " " " 12 " "
Etc., etc.

The lengths of each size are listed for estimates and bids, the same as sewer pipe.

In Fig. 36 is given a diagram for estimating the cost of pipe sewers and subdrains in the Middle West. It may be used elsewhere by noting local conditions and their variation from the conditions assumed, as follows:

(*a*) If the sewers are to be paid for promptly as the work progresses, in cash instead of in assessment certificates, deduct about 10 per cent.

(*b*) Get actual prices on sewer pipe delivered, and add about 8 per cent for additional cost of specials in the average residence district, and 16 per cent in the average business district.

(*c*) Ascertain the character of the soil, and the likelihood of encountering ground water. If the conditions are very favorable, the cost of trenching, refilling, and pipe laying may be materially decreased, even sometimes to 50 per cent of the figures shown in the diagram; while on the other hand, for very unfavorable conditions, the cost shown for these items will have to be increased, sometimes even to 150 per cent.

Example 48. Estimate the cost of a pipe sewer consisting of 1,200 ft. of 18-inch pipe averaging 16 feet deep, and 2,700 feet of 15-inch pipe averaging 12 ft. deep, under average conditions, together with a 6-inch subdrain.

Solution:

1,200 × 2.35 (from diagram) = $3,020 for 18-inch sewer
2,700 × 1.60 (" ") = 4,320 " 15 " "
3,900 × 0.15 (" ") = 585 " 6 " subdrain

Answer. Total estimated cost = $7,925

84. Cost of Brick Sewers. The cost of a brick sewer may be estimated by determining separately the cost of the excavation and refilling and that of the brickwork. The number of cubic yards of each of these items is computed for 1 linear foot length of sewer; and the cost per linear foot is estimated by multiplying the results so obtained by estimated costs per cubic yard of excavation and brickwork respectively.

(1) *To calculate the number of cubic yards of excavation per linear foot length of sewer, multiply the average depth of sewer trench by the average width, and divide by* 27.

The *average depth* for a circular bottom will approximate the *average depth from the surface to the invert,* while the *average width* will be *at least as great as the internal diameter plus twice the thickness of the brickwork.*

Thus, for a 2-ring (9 inches of brickwork) circular sewer 6 feet in diameter, with grade line 12 ft. deep, the number of cubic yards excavation per linear foot of sewer is:

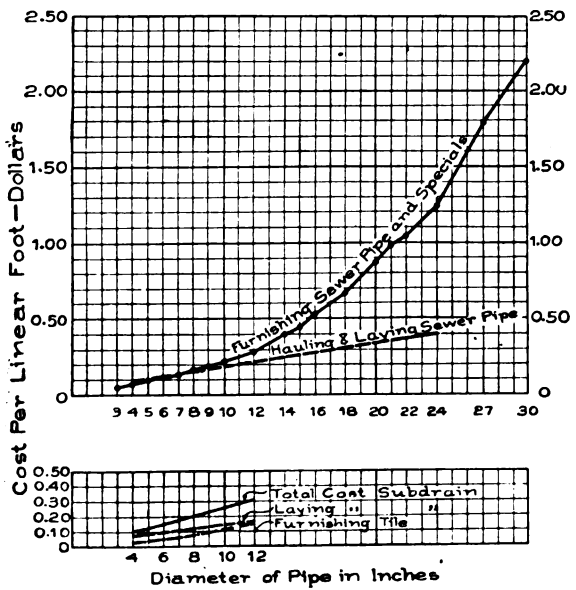
$$\frac{12 \times (6 + 1\frac{1}{2})}{27} = \frac{90}{27} = 3\frac{1}{3} \text{ cu. yds. per linear ft.}$$

The cost of sewer excavation and refilling varies usually from $0.20 *per cu. yd. to* $1.20 *per cu. yd., averaging perhaps* $0.50 *to* $0.75 *per cu. yd.*

DIAGRAMS FOR ESTIMATING COST OF PIPE SEWERS

Prepared from data collected for average conditions in the Middle West, 1906; ditches braced and partially sheathed; amount of water, moderate; common labor, $1.75 a day; payments to contractor, partly in assessment certificates.

For especially favorable or unfavorable conditions, the cost may vary 50 per cent either way, except for furnishing.


Cost Per Linear Foot—Dollars
Furnishing Sewer Pipe and Specials
Hauling & Laying Sewer Pipe
Total Cost Subdrain
" Laying "
" Furnishing Tile
Diameter of Pipe in Inches

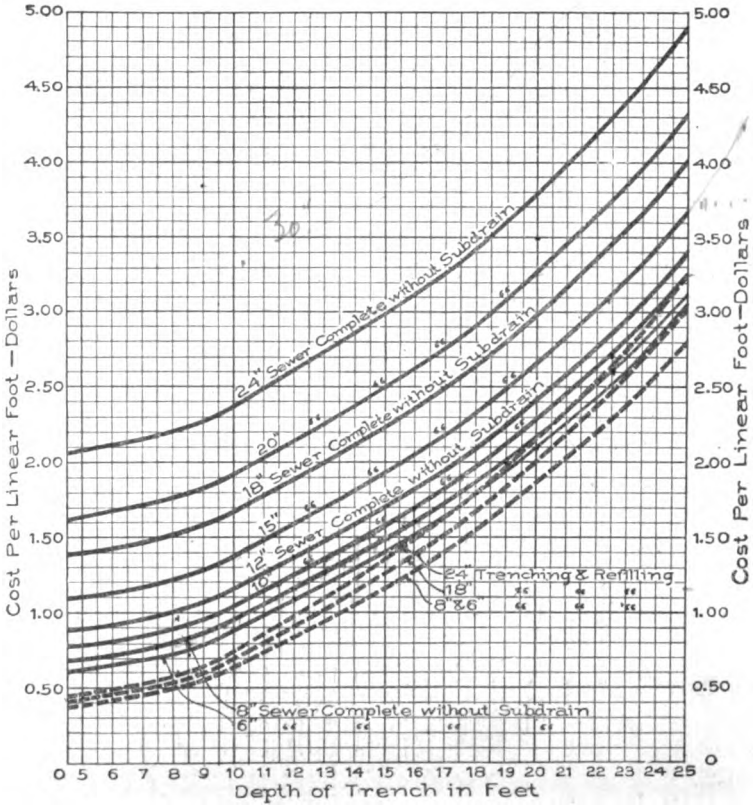
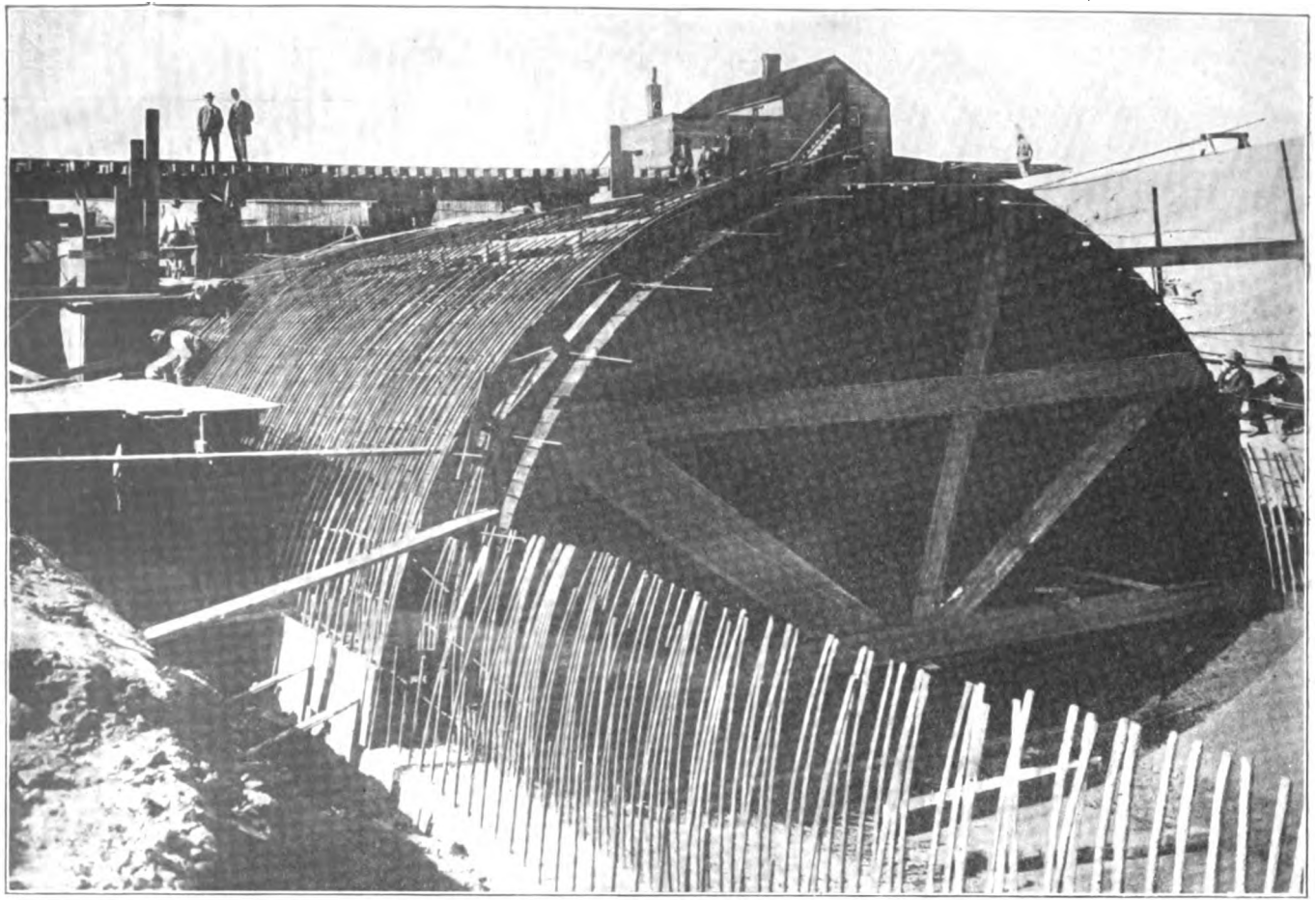

Cost Per Linear Foot—Dollars
24" Sewer Complete without Subdrain
20" " " " "
18" " " " "
15" " " " "
12" " " " "
10" " " " "
8" " " " "
6" " " " "
24" Trenching & Refilling
18" " " "
8" & 6" " " "
Depth of Trench in Feet

Fig. 36. Cost of Pipe Sewers.



HARLEM CREEK PUBLIC SEWER, ST. LOUIS, MISSOURI

View showing forms and reinforcing bars in place. Length of sewer, 4,800 ft. Clear span at lower end, 29 ft.; at upper end, 25 ft. Height, from 19 to 18 ft. Designed for 15-ft. fill.

Courtesy of Expanded Metal & Corrugated Bar Company, St. Louis, Mo.

ROAD ROLLER TESTING A CONCRETE CULVERT

Thus, for average conditions, fairly favorable, the cost of excavation for the 6-foot sewer, 12 feet deep, referred to above, would be $3\frac{1}{3} \times .60 = \$2.00$ per linear foot.

The favorable conditions for low cost per cubic yard, are, large sewers; neither great shallowness nor excessive depth; little water; soil firm enough not to require much bracing, yet not hard enough to require to be picked; and the use of excavating machinery. The opposites of these conditions give the unfavorable conditions.

(2) *The number of cubic yards of brickwork per linear foot* of brick sewers, may be taken from Tables XII and XIII, which are taken mainly from Gillette's *Handbook of Cost Data.*

TABLE XII

Cubic Yards per Linear Foot of Brick Masonry in Circular Sewers

Diameter	One Ring	Two Rings	Three Rings
2 ft. 6 in.	0.125	0.283	
3 " 0 "	0.147	0.327	
3 " 6 "	0.169	0.371	
4 " 0"	0.191	0.415	
4 " 6 "	0.213	0.418	
5 " 0 "	0.234	0.502	0.802
5 " 6 "	0.256	0.544	0.867
6 " 0 "	0.278	0.589	0.933
6 " 6 "		0.633	0.998
7 " 0 "		0.677	1.063
7 " 6 "		0.720	1.128
8 " 0 "		0.764	1.194
8 " 6 "		0.807	1.260
9 " 0 "		0.851	1.325
9 " 6 "		0.895	1.390
10 " 0 "		0.938	1.456

TABLE XIII

Cubic Yards per Linear Foot of Brick Masonry in Egg-Shaped Sewers

Dimensions	One Ring	Two Rings	Three Rings
ft. in. ft. in.			
2-0 by 3-6	0.128	0.286	
2-6 " 3-9	0.154	0.341	
3-0 " 4-6	0.182	0.396	
3-6 " 5-3		0.451	0.725
4-0 " 6-0		0.506	0.808
4-6 " 6-9		0.561	0.891
5-0 " 7-6		0.617	0.974
5-6 " 8-3		0.673	1.056
6-0 " 9-0		0.729	1.140
6-6 " 9-9		0.785	1.223

The cost of brick masonry in sewers usually varies from \$8.00 *to* \$14.00 *per cubic yard, averaging perhaps* \$9.50 *to* \$12.00.

Thus, under average conditions, the cost, per linear foot, of the brick masonry of the two-ring, 6-foot circular brick sewer mentioned above, would be about 0.589 cu. yds. (from Table XII) × \$10.50 per cu. yd. = \$6.17 per foot. It will depend upon the grade of brick used, their cost per 1,000, the cost and proportions of cement and sand in the mortar, the wages of brick masons, the size and depth of the ditch, etc.

Example 49. Estimate the cost, under fairly favorable conditions, as to excavation and brickwork, of a 10-foot, 3-ring, circular brick sewer 1,875 ft. long, averaging 10 ft. deep.

Solution:

$$\text{Cu. yds. excavation per foot} = \text{about } \frac{10 \times 13}{27} = 5$$

(allowing 13 ft. width of trench, to provide a little extra room for bracing).

Since the conditions are fair, assume \$0.60 per cu. yd. as cost of excavation and refilling.

The brickwork = 1.456 cu. yds. per linear foot (Table XII); and since the conditions are fair, we shall assume a cost of \$9.50 per cu. yd.

Then the estimate will be as follows:

Excavation and Refilling,	5 × \$0.60 =	\$ 3.00 per lin. ft.
Brickwork	1.456 × 9.50 =	13.83 " " "
Total		\$16.83 " " "

1,875 × 16.83 = \$31,556 for total cost, to which, however, it may be wise to add, say, 5 to 10 per cent for contingencies unforeseen.

Answer. About \$33,500.

85. Cost of Concrete Sewers. The cost of concrete sewers may be estimated by a method precisely similar to that described in Art. 84, above, for brick sewers—namely:

(1) *Compute the cubic yards of excavation per linear foot of sewer* $\left(= \frac{\text{average depth} \times \text{average width}}{27}\right)$, *and multiply by the estimated cost per cubic yard, which will be from* \$0.20 *to* \$1.20, *usually* \$0.50 *to* \$0.75.

(2) *Compute the number of cubic yards of concrete per linear foot of sewer*

$$\left(= \frac{\text{total area of concrete in square feet in a cross-section of the sewer}}{27}\right)$$

and multiply by the estimated cost of the concrete per cubic yard, which will be from \$6.50 *to* \$12.00, *usually from* \$7.50 *to* \$9.50.

(3) *In the case of reinforced concrete sewers, compute the number of pounds of steel reinforcing per linear foot of sewer, and multiply by* \$0.04 *to* \$0.05 *per lb.*

The details of designs for concrete and reinforced concrete sewers vary so much that no tables can be given, as for brick sewers, showing the cubic yards of concrete per linear foot of sewer.

The cost of the concrete will depend upon the costs of cement, sand, and broken stone or gravel, and on their proportions; on the size and depth of the trench and its freedom from water; on the cost of labor, etc.

86. Cost of Manholes, Combined Manholes and Flush-Tanks, Flush-Tanks, Lampholes, and Deep-Cut House Connections. Under these headings the following data of cost will be found valuable:

Manholes. Under average conditions, the cost of brick manholes of the design shown in Fig. 9, will be *about* \$40 *for* 8 *ft. depth of sewer.* For greater depths, *add about* \$3 *per foot of additional depth.*

Combined Manholes and Flush-Tanks. Under average conditions, the cost of these may be estimated at \$80, *plus* \$4 *per foot of additional depth of sewer over* 8 *ft.* This is for about 500 gallons' capacity of the flush-tank part.

Flush-tanks of 500 gallons' capacity, under average conditions, may be estimated to cost *about* \$60 *each.*

Lampholes, such as shown in Fig. 10, may be estimated at *about* \$10, *plus* \$0.35 *per foot of additional depth over* 8 *feet.*

Deep-cut house connections (see Fig. 8) may be estimated at \$2.00 to \$3.00 *each,* according to the depth of the sewer.

87. Engineering and Contingencies. In estimates of the cost of a sewer system, it is necessary to allow for unforeseen contingencies and for the cost of the engineering work. From 5 per cent to 20 per cent is usually added to the estimated cost on these accounts, depend-

ing upon the certainty or uncertainty of the knowledge of all the conditions.

EXAMPLE FOR PRACTICE

88. *Example* 50. Estimate the cost of the sewer system shown below, the conditions being assumed to be average. (NOTE: See Articles 84 to 87, inclusive.)

PRELIMINARY ESTIMATE OF COST OF SEWER SYSTEM FOR

ITEM	APPROX. QUANTITY	COST	
		Unit	Total
4-ft. brick sewer, 2 rings, 8 ft. average depth	850 ft.		
3-ft. " " 2 " 10 " " "	625 "		
24-in. pipe sewer, 9 ft. average depth	3,780 "		
18 " " " 11 " " "	1,740 "		
12 " " " 14 " " "	2,640 "		
8 " " " 10½ " " "	46,800 "		
Manholes 12 " " "	68		
Comb. M.H.& F.T. 10 " " "	18		
Lampholes 11 " " "	38		
Total of above			
Engineering and Contingencies, 10 per cent of above,			
Total estimate of cost			*

* Answer. About $82,500.

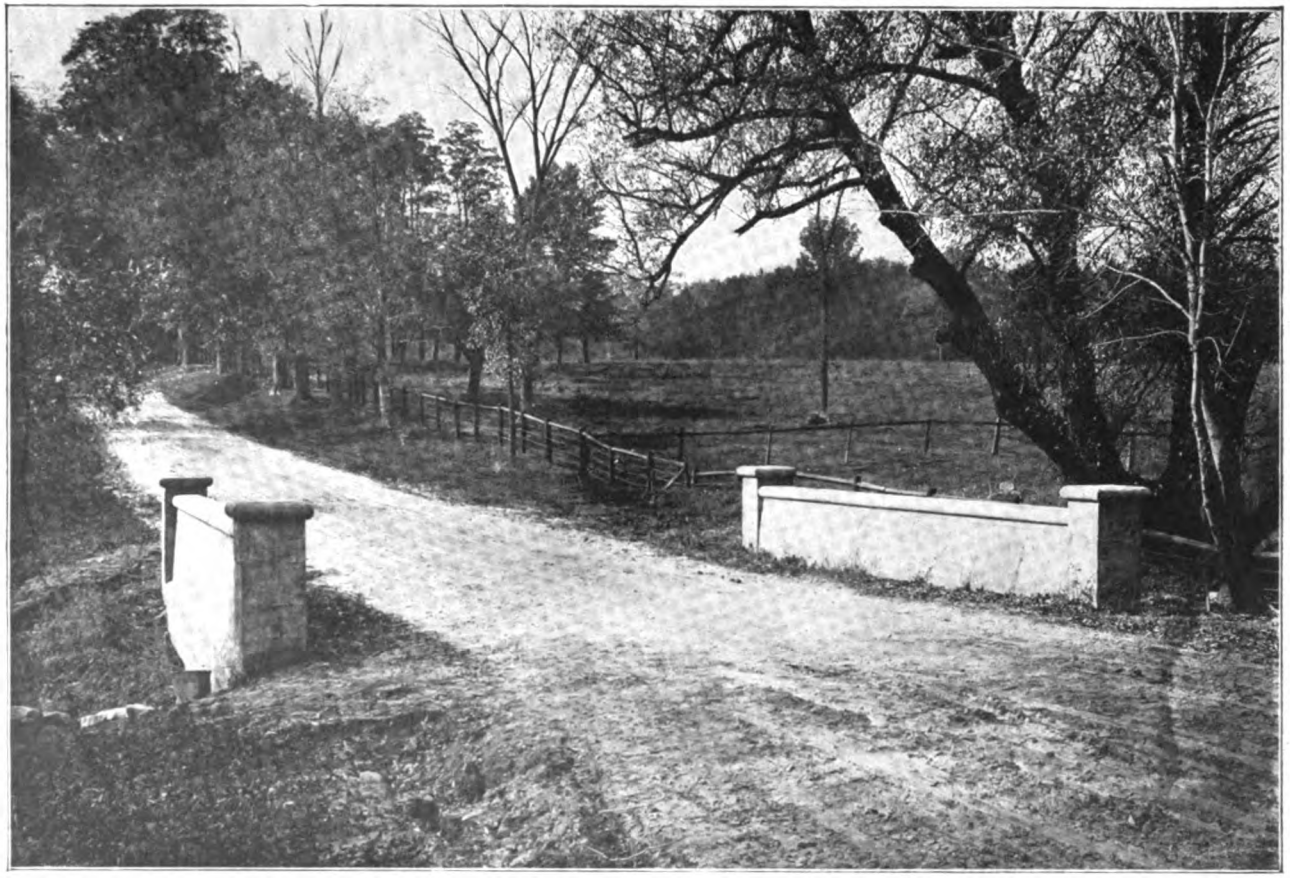
89. Methods of Paying for Sewers. This is another question which comes up early in determining whether a city can or will build or extend a sewer system.

Three methods are in common use in paying for sewers, as follows:

(1) *The City as a whole may pay the entire cost.* When this plan is followed, all or part of the money may be raised by selling bonds, or all or any part may be raised at once by taxation.

In some States, cities are given a right to levy a *sewer tax* of a certain rate for a certain number of years in advance, and to anticipate the proceeds of this tax by issuing *sewer warrants.*

Often, when it comes to the construction of sewers, the City will be found to have already issued bonds to the highest legal amount, to build waterworks, an electric light plant, etc., so that no money for sewers can be raised from bonds.



CULVERT AT LENOX, MASSACHUSETTS

Showing concrete parapet walls. The effect is more pleasing than that produced by the more usual pipe rail fence.

Courtesy of Massachusetts Highway Commission.

(2) . *The entire cost of the sewers may be assessed against the property abutting upon or adjacent to the sewer.* Here the legal principle is that the assessment must be in proportion to the benefit received. Property abutting directly upon the sewer receives the greatest benefit, and must be assessed for most of the cost. Sometimes the benefit will be in proportion to the number of feet frontage of the lots abutting on the sewer; and sometimes the benefit per unit lot is considered to be the same in all parts of the city, a large unit size of lot being adopted in the residence part of the city, and a much smaller size in the business section, with often an intermediate size between these two.

The "assessment" is levied upon the completion of the sewer, when the entire cost can be ascertained. Due notice to all property owners assessed must be given, so that they can present objections if they desire. Usually all property owners who desire are allowed to spread the payment of their assessments in equal installments over a considerable period of years, in which case *assessment certificates* are issued to cover the payments. The contractor is often required to take these certificates in payment for the sewer.

(3) *The cost of the sewers may be divided between the City and the property directly abutting upon or adjacent to the sewer.* This seems the fairest way; since, in the first place, the entire city receives benefit from improved sanitation, attractiveness to investors, etc., from a sewer constructed anywhere within its limits; and since, in the second place, any system of sewers for a city should be planned to give outlets of proper size to all parts of the district, which enlarges and deepens the sewers on many streets. On the other hand, the property along the sewer is benefited much more than the rest of the city, and should accordingly pay a much larger proportion of the cost.

The City Council usually has the right to decide what percentage of the cost is to be paid by the City and what by the property along the sewers.

PREPARATION OF PLANS AND SPECIFICATIONS FOR SEWERAGE SYSTEMS

90. Sewer Reconnaissance. When a sanitary engineer is called upon to prepare plans and specifications for a sewerage system, the first thing which he should do is to make a *reconnaissance* or

general study of the entire city and its surroundings, with special reference to its sewerage conditions.

He visits the city and obtains copies of the best *maps* procurable. If these maps do not show the contours or elevations of the surface at different points, he obtains the best procurable information as to such elevations, and enters it upon the maps. Often the elevations of *street grades* will prove sufficient, if better and more detailed information is lacking. If *street profiles* are available, they will of course be of great value.

With maps thus prepared for the purpose, *he rides or walks over all parts of the city*, making himself thoroughly familiar with its *topography* and other features. Some of the information thus obtained may be entered upon the maps. He will note the *present density of population in different sections, and the prospects for future growth.* The presence or absence of *manufacturing industries*, and the future prospects in this line, are of importance. Statistics of the *past growth* of the city will be obtained. Full information regarding the character of the *water supply* and the amount and fluctuations of the *water consumption*, and the distribution of the *water mains* throughout the city, will be of great value. The local *labor conditions*, and the probable *local cost of cement, sand, brick, sewer pipe*, and other needed materials, must be ascertained. All possible information should be secured regarding the *ground water* and the *character of the soil* in different sections of the city. Information about old excavations and about wells can usually be secured, and will give much light on these points.

From his general study of the conditions, including especially the topography, the engineer must decide whether the system of sewerage shall be a *separate* system, or a *combined* system (see Articles 10 to 13, inclusive).

The question of the *outlet* will be one of the most important controlling points to be decided, and the engineer must carefully examine all possibilities in this line. The *number of outlets should be as small as feasible, one outlet being secured if possible.* The outlet must be low enough to drain thoroughly all portions of the district it serves, and should be chosen with a view to safe and satisfactory disposal of the sewage.

Sewage disposal is one of the very important points to be con-

sidered. In the past, most cities have simply discharged their sewage into the nearest available body or stream of water which it was considered could be used without causing damage or injunction suits on account of the pollution. At the present time, cities are being compelled more and more to provide means for purifying the sewage (see Articles 110 to 124); and the engineer, in choosing the outlet and planning the sewers, should always consider it probable that in the not distant future the city will be compelled to use some method of purification, and his plans should be so made as readily to permit this in the future, even if the city builds no sewage purification works at first.

During the reconnaissance, the engineer must constantly be recording the significant information he secures, in a neat and systematic manner in *a standard notebook*, which he keeps for the purpose. *Loose-leaf notebooks* of pocket size have many advantages for this purpose. In the same notebook, he should make all his preliminary computations.

On completing the reconnaissance, the engineer usually makes a *preliminary report* to the city officers, stating the conditions he has found, and his conclusions as to the general features of the system he has decided to recommend as best. He also usually presents at this time some rough estimates of cost.

The city then decides whether or not to adopt the general recommendations of the engineer, and whether to go on with the preparation of plans and specifications.

91. Surveys for Sewer Plans. After the reconnaissance, if it is decided to go ahead with the plans, the next step will be to make the necessary *surveys*. These may usually be divided into three principal parts as follows:

(1) *Surveys of Sewage Disposal Site.* In case a sewage disposal plant is to be built, a survey of the site must be made to secure the data needed for the design. Usually this will include data for a *contour map* of the entire tract, and borings or pits to determine the character of the soil.

(2) *Surveys for the Outlet Sewer.* Transit and level lines must be run, and profiles prepared, to determine the best route for the outlet sewer. Data must be secured for an accurate map and profile of the final location of this sewer.

(3) *Surveys for the Street Sewers.* Usually, existing plats can be found sufficiently accurate to give the dimensions necessary for constructing the *general sewerage map*, without special surveys. Small errors on these plats will not affect the general design, and will not be of much importance in view of the accurate surveys which must be made later during construction. Sometimes a few measurements with tape-line and transit must be taken in special localities. Usually the main part of the surveys for the street sewers consists in running *lines of levels* along all the streets on which there is possibility of planning sewers, in order to secure the data necessary to make the *sewer profiles* of all the sewers.

These levels should be referred to the *city datum*—that is, the reference level above which all city elevations are given. If such a datum has not already been adopted, one should be established, and marked by a *permanent bench-mark.* A six-inch iron pipe set six feet in the ground, filled and surrounded with concrete, makes a good, permanent bench-mark. The top, not quite filled with concrete, projects a little above the ground, and a copper bolt is set in the concrete at the top, the top of the bolt constituting the bench-mark. The pipe should have a hinged iron cap to protect the bolt.

In running the level, no effort should be made to trace out the main lines of sewers and their branches, but *each street should be surveyed by itself.* A zero point should be taken at some definite point (such as the center line, or one of the side lines, of a cross-street) at one end of the street, and *station points* 100 feet apart determined by continuous measurements with a steel tape. These stations should be numbered continuously from the zero point, intermediate points being located, in the usual way, by *plus* distances from the preceding station. Thus station 9 + 72 is 972 feet from the zero point.

The exact plus of each side line of each cross-street, and of points opposite other important things, should be determined and recorded in the notebook, to give measurements to be used in preparing the profiles, and in checking the map.

All lines of levels must be checked. At the end of each street, the leveling can be extended across to an adjacent street, and checked with the line of levels on that street.

Numerous bench-marks should be established around the city,

located on permanent points, such as the tops of the foundation walls of buildings.

92. Sewerage Plans. From the data obtained by the surveys, the sewerage plans must be prepared. These will usually consist of a large number of separate sheets, the following being a list of the sheets of one particular set of plans, for a separate system of pipe sewers.

1. Index Sheet. (Giving the contents of all other sheets.)
2. General Sewerage Map.
3. General Map of Sewage-Disposal Plant.
4. Detailed Plans of Septic Tank. (For the Sewage-Disposal Plant.)
5. Detailed Plans of Filter Beds. (For the Sewage-Disposal Plant.)
6. Plans of Standard and Drop Manholes, and Lampholes.
7. Plans of Combined Manholes and Flush-Tanks.

8 to 33. Profile Sheets. (Showing profiles of all the sewers.)

In other cases, separate sheets may be needed for many other things, as, for example,

Details of Brick Sewers, of different sizes.
" " Concrete Sewers, " "
Plans of Flush-Tanks.
" " Catch-Basins.
" " Street Inlets.
" " Sewage Pumping Station.
Etc., etc.

For the sake of convenience and of neatness and system, *all the sheets of a set of sewerage plans should be made of a standard size* (*one or two can be made larger and folded to the standard size*), *and they should be bound together in regular book covers*, 18 inches by 24 inches being a convenient standard size of sheet for most cases.

Fig. 37 is a photographic view of such a cover containing a set of sewerage plans. The cover protects the sheets from injury, and is so arranged that any sheet can readily be removed and replaced A cover like that shown costs about $1.50.

The original drawings were all made on tracing cloth, except the profiles, which were made on transparent profile paper. Thus all the sheets can readily be reproduced by the process of blue-printing, and only the blue-print sheets are used on the work or by the City, the engineer retaining the original tracings in his office, where they can be kept safe.

In such a set of plans, the sheets should be numbered in order (see Figs. 38 and 39); and a *standard title* (see title of Fig. 38) should

be adopted for all sheets which will require few changes of the different sheets.

Sewerage Map. In Fig. 38 is shown a reduced copy of an actual *sewerage map* of a separate system of sewers for a small town. The original size of the map shown was 36 inches by 24 inches, so that folding it once reduced it to the 18-inch by 24-inch size.

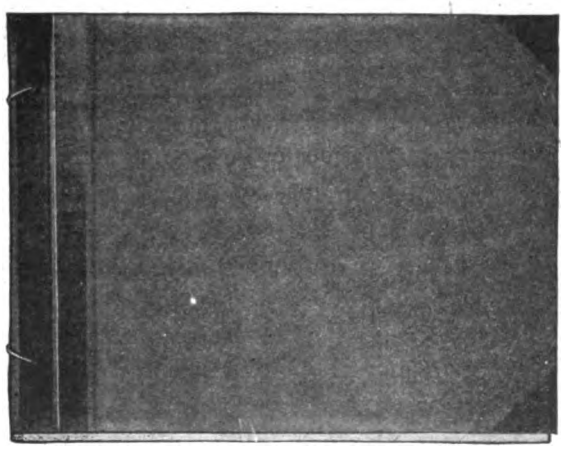


Fig. 37. Standard Cover for Sewerage Plans.

The original scale of the map shown was 200 feet per inch; but for larger places, 300 feet or even 400 feet per inch may be sufficient, since large-scale maps of all the individual sewers appear on the profile sheets.

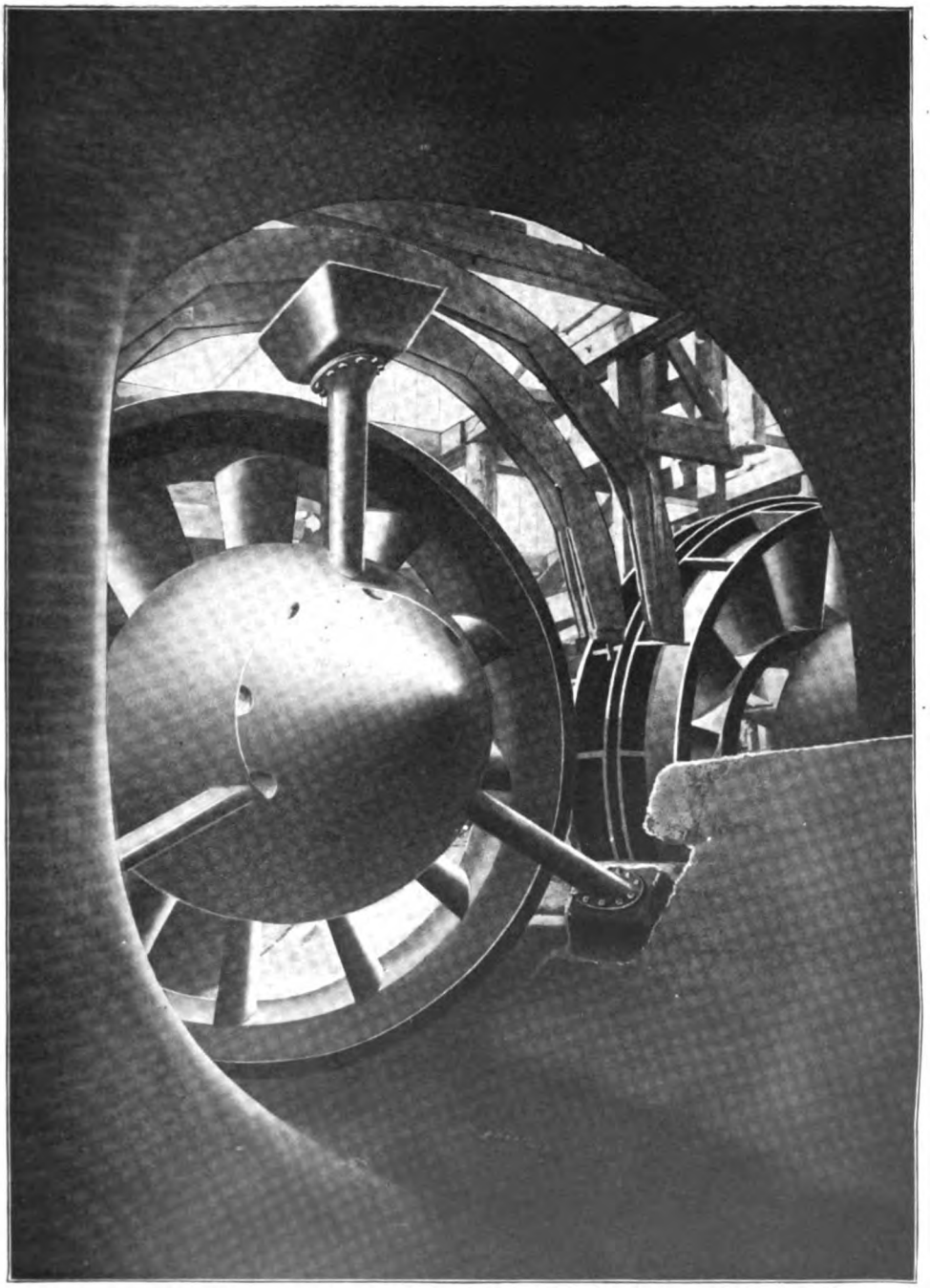
The lines of sewers in a system such as shown in Fig. 38, ought to be restricted as far as possible to the streets on which the lots front. Sewers on cross-streets add to the mileage of sewers without serving additional lots, and are useless except for connecting other sewers.

The manholes, lampholes, flush-tanks, etc., should be numbered systematically, something as shown in Fig. 38, no two structures of the same kind having the same number. This avoids danger of duplication where the same structure is shown on two or more sheets, as is often the case.

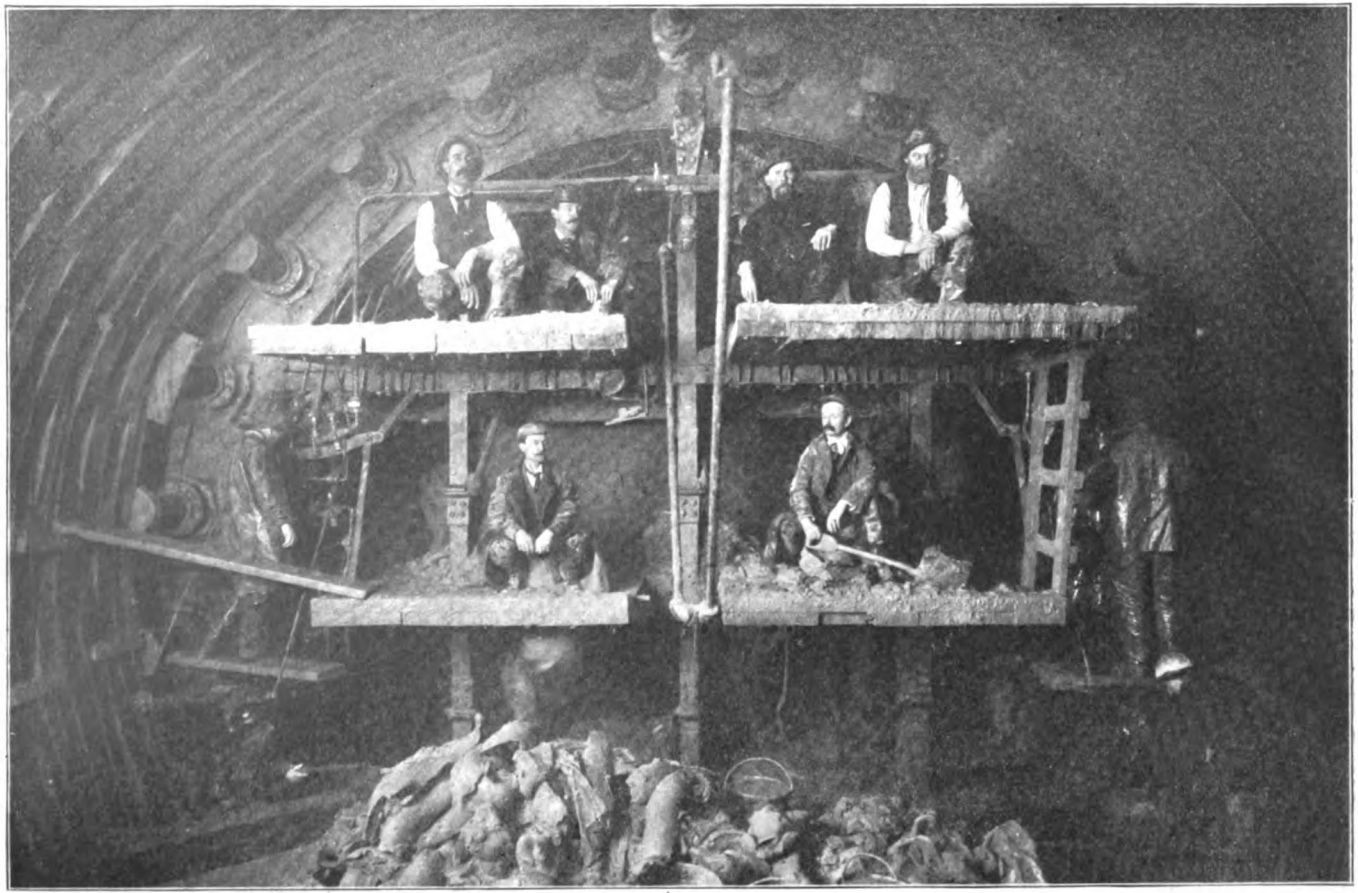
Sewer Profiles. In Fig. 39 is shown a sample profile sheet from an actual set of plans.

The original profile was made on "Plate B" transparent profile paper, so that the profiles can be reproduced easily by blue-printing, the same as the other drawings. The sheets were cut to the standard size, 18 inches by 24 inches, to bind with the other drawings.

The profiles should be made in systematic order of the streets, each



DEFLECTOR RING AND HUB OF SCREW PUMP, CHICAGO SYSTEM OF INTERCEPTING SEWERS
Erected at 39th Street Pumping Station.



CONSTRUCTING THE LARGEST SEWER IN THE UNITED STATES

View of men at work in tunneling shield; wooden forms also shown. Sewer lined with brick laid in "Utica" hydraulic cement. View of 39th Street intercepting sewer, Chicago, Ill.

Courtesy of Meacham & Wright, Chicago, Ill.

street completed before beginning the next, instead of trying to follow up the main lines of the sewers and their branches.

The profile sheets show large-scale maps of the individual

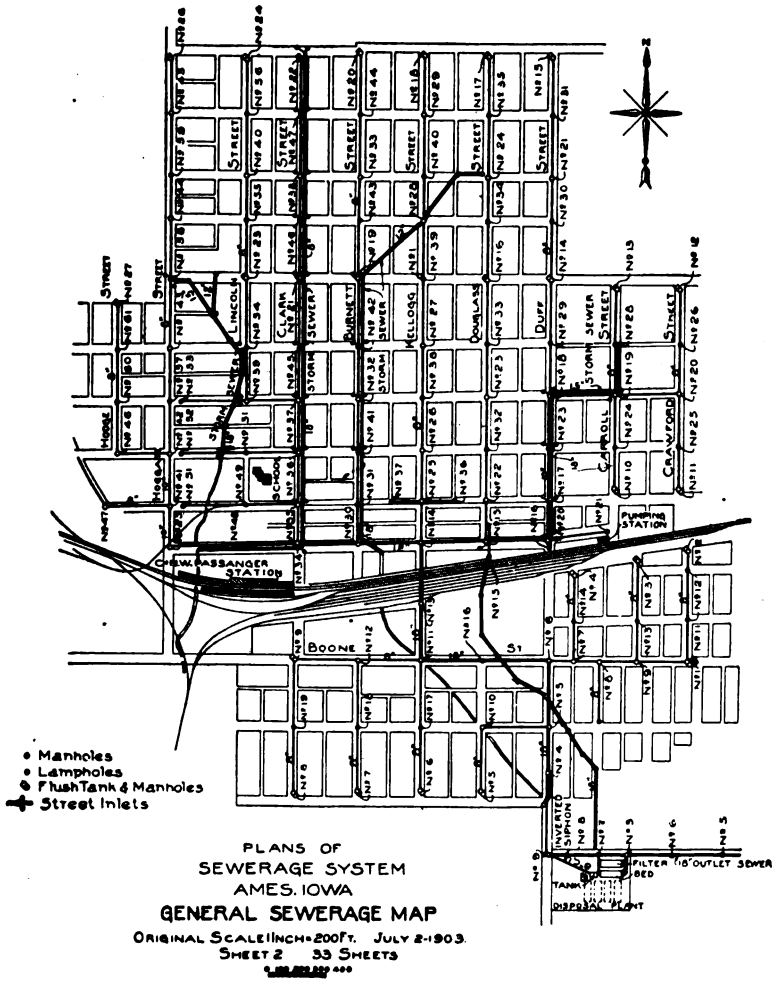


Fig. 38.

sewers immediately below their profiles, to permit the exact location of manholes, etc., and of the sewer itself in the street.

93. Specifications for Sewers. Besides the plans, it will be necessary for the sewerage engineer to prepare precise instructions regarding all matters of importance not fully shown by the plans,

likely to come up during the construction of any part of the sewerage system. Such instructions are called *Specifications*.

An ordinary set of sewer specifications will consist of three parts:

(1) A *Notice to Contractors*, or form of advertisement for the city officers, to use in advertising for bids.

(2) A *Form for Proposal*, with suitable blanks, on copies of which, furnished by the city, all contractors are required to make their bids.

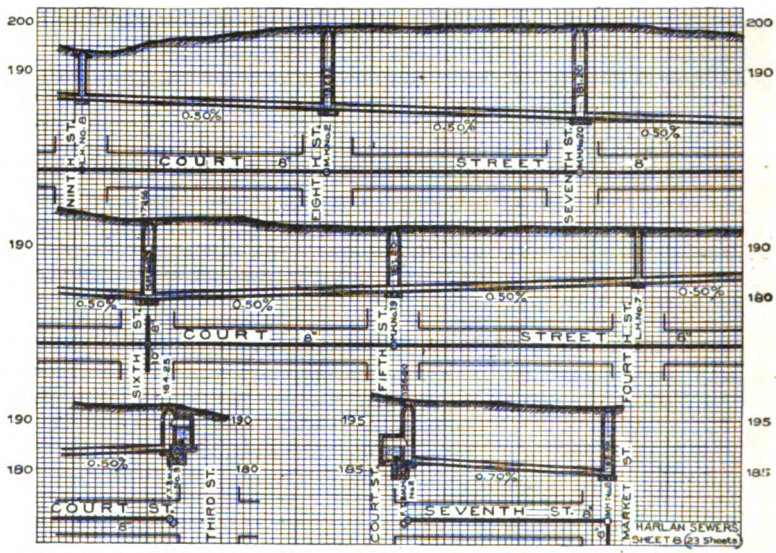


Fig. 39. Typical Sewer Profile Sheet.

(3) *The Specifications Proper.* These again will consist of two main divisions:

(*a*) General clauses, relating to payments, guarantees, etc., and to general features of the work.

(*b*) Specific clauses, specifying the exact details of different parts of the work.

A copy of an actual set of specifications for the construction of a separate system of pipe sewers, with a sewage-disposal plant, is given herewith:

CITY OF_____, _____

SPECIFICATIONS

FOR

SEWERS AND SEWAGE-DISPOSAL PLANT

NOTICE TO CONTRACTORS

The Incorporated City of———————,———., will receive

sealed bids until————, ————, at ————————; (1) for the construction of a sewage-disposal plant, consisting of a sewage tank of about ————gals. capacity, and —— sand filter beds, each of about——sq. ft. area; and (2) for the construction of sewers as follows: about ——ft. of 18-inch, —— ft. of 15-inch, —— ft. of 12-inch, —— ft. of 10-inch, and —— ft. of 8-inch, with suitable appurtenances, all in accordance with plans and specifications prepared by ————, Engineer, ————, and now on file in his office and with the City Clerk. All bids must be accompanied with certified checks, approximately in the amount of 5 per cent of the bid, made payable without recourse to the City of————,————. The City reserves the right to reject any or all bids, to waive defects, and to accept any bid. All bids must be in sealed envelopes, marked on the outside "Sewerage Bids," and addressed to————, City Clerk.

INSTRUCTIONS TO BIDDERS, AND GENERAL SPECIFICATIONS

(1) *Items.* The items of work intended to be covered by these specifications are those required for the entire completion of the System of Sanitary Sewers for the City of————————, ————, according to the plans prepared by————, Engineer, and include the following:

(*a*) The construction of a Sewage-Disposal Plant, including a sewage tank of about ——— gallons capacity, and —— sand filter beds, each of about —— sq. ft. area, and including all valves, sewer pipes, outlets, etc.

(*b*) The construction of Sewers as follows:

18-inch	Ft.
15-inch	"
12-inch	"
10-inch	"
8-inch	"
Manholes	"
Lampholes	"
Combined Manholes and Flush-Tanks,	"

together with subdrains as directed by the City.

(2) *Application.* These general specifications and instructions to bidders shall apply to all items of workmanship or materials enumerated above or hereinafter mentioned.

(3) *Definitions of Terms.* Wherever the word "City" is used in these specifications, it shall be understood to mean the Incorporated City of————, ———., acting through the Mayor and Council, or their duly authorized representatives. Wherever the word "Contractor" is used in these specifications, it shall be understood to mean the person or firm employed to do all or any part of the work or furnish all or any part of the material for the Sanitary Sewerage System. Wherever the word "Engineer" is used in these specifications, it shall be understood to mean the Engineer employed by the City to design or supervise the construction of all or any part of the Sanitary Sewerage System.

(4) *Bids.* All bids must be on blanks furnished by the City for the purpose. The blanks can be obtained from ————————, City Clerk ————, ————., or from ————, Engineer, ————, ————.

All bids must be enclosed in sealed envelopes addressed to————, City Clerk,————, ———., and plainly marked on the outside with the words "Sewerage Bids."

Each bid must be accompanied with a certified check approximately in the sum of 5 per cent of the bid, and made payable without recourse to the City Treasurer, ————————,————.

The City reserves the right to reject any or all bids, to waive defects, and to accept any bid.

(5) *Certified Checks.* The certified check mentioned above will be forfeited as damages to the Incorporated City of ————————, ————., unless the Contractor enters into contract and furnishes bonds satisfactory to the Mayor and Council within 12 days after the contract has been awarded to him. Certified checks not so forfeited shall be returned to the bidders as soon as the contract is signed and satisfactory bonds are furnished.

(6) *Bond.* A bond satisfactory to the Mayor and Council shall be furnished by the Contractor, approximately in the amount of 50 per cent of the contract price.

(7) *Time.* The Contractor shall begin work within 3 weeks after the contract is awarded to him, and shall entirely complete the work on or before ————————, ————.

(8) *Sub-contracts.* No sub-contracts shall be awarded to parties unacceptable to the City.

(9) *Progress of the Work.* The work shall be prosecuted at a rate to enable its completion within the time specified; and should the Contractor fail to do this, the City may, after giving ten days' written notice, take over the work and complete it at the Contractor's expense.

(10) *Penalties.* Should the Contractor fail to complete the work at the time specified, he shall forfeit to the City a sum equal to all damages to it resulting from the failure to complete the work at the time specified.

(11) *Delays.* No claims for damages shall be made against the City on account of delays in delivery of materials or performance of work; but should there be unduly prolonged delays in the delivery of any materials or the performance of work on the part of the City, the Contractor shall be entitled to corresponding extension of time.

(12) *Obstructions.* The Contractor shall carry on the work in such a way as to obstruct the city streets as little as possible, and so as not at any time entirely to shut off passage of teams and pedestrians at any place. He shall provide temporary crossings satisfactory to the City for this purpose wherever necessary.

(13) *Precautions.* The Contractor shall take all necessary precautions to prevent injury to the public or to his workmen or to stock, such as providing crossing plank, fencing off his work, keeping lanterns burning at night, etc. He shall hold the City harmless against all claims for damages.

(14) *Plans and Specifications.* The City's plans and these specifications shall be a part of the contract, and all materials and workmanship shall be in accordance with them.

(15) *Supervision.* All materials and workmanship shall be subject to the supervision and inspection of the City and of its Engineer or other authorized representative. Instructions as to the details of the work shall be carried

out, and rejected materials and work shall be promptly removed at any time discovered.

(16) *Quality of Materials and Workmanship.* All workmanship and materials shall be of the best quality.

(17) *Quantities.* The quantities named in the notice to contractors, the form of proposal, or in these specifications, are approximate only. The City shall have the right to vary them; and, if so varied, the total contract price shall be increased or diminished at the rates named per unit in the contract.

(18) *Extra Work.* No extra work shall be done without written orders from the City or its specially authorized representatives placed in charge of the work. In case extra work becomes necessary, it shall be done by the Contractor if so ordered, and shall be paid for by the City on the basis of actual cost, *plus* 10 per cent; but no extra work will be paid for unless ordered in writing by the proper authority at the time undertaken.

(19) *Changes in Plans.* The City shall have the right to make changes in plans. In making such changes, the unit prices named in the contract shall be used, as far as possible, in calculating the changes in price on account of changes in the plans, and where these do not apply, the changes in price, unless a special agreement between the City and the Contractor as to prices is made at the time the changes are ordered, shall be calculated on the same basis as extra work.

(20) *Claims.* The Contractor shall guarantee the payment of all just claims for materials or labor in connection with his contract. Preliminary to the payment for any work, he shall, if required by the City, present evidence satisfactory to the Mayor and Council that all bills for materials and labor have been paid, and any or all payments may be reserved until such evidence has been presented. If the payment of any just claim shall be deferred more than four weeks after written notice has been given concerning it to the Contractor, the City may proceed to pay such claim out of any money due the Contractor.

(21) *Payments.* Payments shall be made as follows:

(NOTE: Fill in, in this blank, whether the payment is to be made in cash, in sewer warrants, sewer certificates, or otherwise. Also whether payments are to be made monthly as the work progresses, or reserved until completion, the former plan being usual for cash payments, and the latter for payments in certificates.)

All payments shall be on estimates prepared by the Engineer and approved by the Council, of materials delivered and work performed; and in case of all payments made prior to the completion of the contract, 15 per cent of the estimate shall be reserved until the final payment on completion of the work.

No payment shall be considered as releasing the Contractor from obligation to remove and make good defective work and materials when discovered at any time.

Two per cent of the total cost may be reserved by the City for one year after the completion of the work, and any part of this reserve may be used to make good defects developed within that time from faulty workmanship and materials, provided that notice shall first be given the Contractor, and that he may promptly make good such defects himself if he desires.

(22) *Guarantee.* The Contractor shall guarantee the workmanship and materials for one year, and keep the system in repair after completion, as provided in clause 21 above.

(23) *Risks.* All materials and work will be at the risk of the Contractor until the final acceptance of the same.

(24) *Cleaning Up.* On completion of each part of the work, all rubbish and unsightly materials must be removed and disposed of as directed by the City, and the streets and grounds left in neat condition. For the sewers, each two blocks must be cleaned up immediately on completion, and on the completion of the entire contract shall be further put in good shape if needed.

MATERIALS

(25) *Vitrified Sewer Pipe.* All sewers shall, unless special permission be given to use cement sewer pipe, be constructed of first-quality salt-glazed, vitrified clay sewer pipe, of the hub-and-spigot pattern, of standard thicknesses and dimensions of hubs. The dimensions of hubs shall be sufficient to leave an annular space for cement of at least $\frac{3}{8}$-inch thickness for 8-inch and 10-inch pipe, and $\frac{1}{2}$-inch thickness for larger diameters.

Pipe may be furnished in lengths of 2, $2\frac{1}{2}$, or 3 feet. All pipe and specials shall be sound and well burned, with a clear ring, well glazed and smooth on the inside, and free from broken blisters, lumps, or flakes which are thicker than $\frac{1}{8}$ the nominal thickness of the pipe and whose largest diameters are greater than $\frac{1}{8}$ the inner diameter of said pipe; and the pipe and specials having broken blisters, lumps, and flakes of any size shall be rejected unless the pipe can be so laid as to bring all of these defects in the top half of the sewer. No pipe having unbroken blisters more than $\frac{1}{4}$ inch high shall be used, unless these blisters can be placed in the top half of the sewer. Pipes or specials having fire-checks or cracks of any kind extending through the thickness shall be rejected.

No pipe shall be used which, designed to be straight, varies from a straight line more than $\frac{1}{8}$ inch per foot of length; nor shall there be any variation between any two diameters of a pipe greater than $\frac{1}{24}$ the nominal diameter.

No pipe shall be used which has a piece broken from the spigot end deeper than $1\frac{1}{2}$ inches or longer at any point than $\frac{1}{4}$ the diameter of the pipe; nor which has a piece broken from the bell end if the fracture extends into the body of the pipe, or if such fracture cannot be placed at the top of the sewer. Any pipe or special which betrays in any manner a want of thorough vitrification or fusion, or the use of improper or insufficient materials or methods in its manufacture, shall be rejected.

(26) *Sewer-Pipe Specials.* All T- and Y- junction curves, etc., required shall be furnished and set without extra charge, and shall conform to the pipe specifications as to quality. Y's for house connections may be required every 25 feet on the average, and shall be closed by vitrified stoppers cemented over sand.

(27) *Drain-Tile.* All drain-tile shall be best-quality vitrified agricultural drain-tile in one-foot lengths. All junctions and inspection openings shall be made with suitable T- and Y- junctions and curves, furnished and set without extra charge.

(28) *Brick.* All brick used on the work shall be sound, partially vitrified, well-shaped brick, equal to No. 2 paving brick.

(29) *Cement.* All cement used shall be ——, ——, ——, ——, ——, ——, or —— Portland Cement, perfectly fresh, and not damaged in any particular. It shall be subject to the Standard specifications of the American Society for Testing Materials, and will be rejected if it does not meet these requirements. All cement shall also be subject to close inspection as it is used on the work, and damaged cement will be rejected and must be promptly removed.

(30) *Sand.* All sand shall be clean, sharp, and coarse. All sand for mortar for sewer joints or brick masonry must have all pebbles screened out.

(31) *Broken Stone and Pebbles.* The aggregate for concrete shall consist of either broken stone or screened pebbles passing a 2½-inch ring for ordinary concrete, ~~and a 1½-inch ring for the septic tank.~~ The materials must be sound and hard and durable. The sand must be screened out of pebbles used; but the fine materials need not be screened out from broken stone, a reduction being made in the amount of sand used, approximately equal to the amount of stone dust.

(32) *Cast Iron.* All cast iron shall be good, tough, gray iron, free from defects. Castings shall be smooth and free from blowholes or other flaws.

(33) *Cast-Iron Water-Pipe.* All cast-iron pipe shall be cast of the hub-and-spigot pattern, of standard weights for water-pipe for light pressures. The pipe shall be well coated.

(34) *Valves.* All valves shall be iron body, brass-mounted, hub-end, double-gate, water valves, well coated, of the —————— or of equal make acceptable to the Engineer.

(35) *Valve Boxes.* All valve boxes shall be —————— extension boxes with 5¼-inch shafts, or some equal make acceptable to the Engineer.

MORTAR AND CONCRETE

(36) *Mortar.* All mortar for brickwork or other masonry shall be made of one part of Portland cement to three parts of sand; and all mortar for sewer joints, of one part of cement to one of sand, both ingredients being measured loose and thoroughly mixed. All mortar shall be mixed fresh as used, and any mortar which has begun to set shall be thrown away and not used at all on the work.

(37) *Concrete.* All masonry shown on the plans to be made of concrete shall be constructed with Portland cement, sand, and either broken stone or screened pebbles passing a 2½-inch ring, in the proportions 1-3-5 for ordinary work, ~~and 1-2-3½ for the septic~~ tank, the cement being measured packed as it comes in sacks or barrels, and the sand being measured loose as thrown into the measuring box with shovels. The proportions shall be determined by suitable measuring boxes, or by the use of wheelbarrows. In case of hand-mixing, the sand and cement shall first be thoroughly mixed dry until the color of the mixture is uniform. They shall then again be mixed with water, and then again with the freshly wet aggregate, each mixing being very thorough, and sufficient to secure perfect mixture of the materials. If a machine mixer is used, it shall be of a make acceptable to the Engineer, and shall be so used as to give very thorough mixing. Just enough water shall be

used to make the concrete slightly quake when thoroughly rammed, the water freely flushing to the surface under the ramming.

In depositing, the material shall be deposited in layers not exceeding 6 inches in height, and thoroughly rammed. Where work is left for the night, the layers shall be racked back. Where fresh concrete is deposited on work which is already set or begun to set, the surface shall first be thoroughly cleaned and wet, and washed with a coat of liquid neat cement. After the concrete is deposited, great care shall be taken not to disturb it until the work is thoroughly set. The work shall be protected from the sun, and shall be wet ~~from time to time~~, until it is thoroughly set.

TRENCHING, PIPE-LAYING, REFILLING, ETC.

(38) *Excavation.* The excavation shall be made ~~exactly~~ to line and grade as indicated by stakes set by the Engineer. At the bottom, the trench shall have a clear width at least one foot greater than the external diameter of the body of the pipe. The last four inches shall be excavated only a few feet in advance of the pipe-laying, by men especially skilled, measuring from an overhead line set parallel to the grade line of the sewer. The bottom of the trench shall be rounded to fit the pipe; and holes shall be dug for the bells so as to give a uniform bearing, and permit the proper construction of the sewer joints on the under side of the pipe. The earth taken from the trench shall be deposited neatly at the sides, in such manner as to obstruct the streets as little as possible; and a clear space of two feet next the trench shall be left on the side on which the Engineer places his stakes. Great care shall be taken to preserve and not to cover up the Engineer's stakes.

(39) *Sheathing.* Wherever necessary to prevent caving of the banks or injury to adjacent pipes or buildings, the Contractor shall, at his own expense, brace and sheath the trenches sufficiently to overcome the difficulty to the satisfaction of the Engineer. If such bracing and sheathing is left permanently in the trench by order of the Engineer, it shall, on refilling, be cut off one foot below the surface and shall be paid for by the City at the price named in the contract; but otherwise the Contractor will receive no extra compensation for it.

(40) *Water in Trenches.* In general, all water encountered in trenches must be drained away through the sub-drains or pumped or bailed out, and the trench must be kept dry for the pipe-laying. In no case shall the sewers be used as drains for such water, and the ends of the sewer shall be kept properly blocked during construction. All necessary precautions shall be taken by the Contractor to prevent the entrance of mud, sand, or other obstructing material into the sewers or subdrains; and on completion of the work, any such materials which may have entered must be cleaned out and the sewers and subdrains left clean and unobstructed.

(41) *Refilling.* In refilling, earth free from stones shall be carefully placed by hand under and around the pipe and to the height of two feet above the top of the sewer, and thoroughly and carefully rammed in layers of not more than six inches' depth.

The remainder of the refilling shall be carefully done. Scrapers may be used if desired. The refilling shall be thoroughly flooded by the Contractor according to the direction of the Engineer, the City furnishing the water free

at the hydrant; but the refilling shall be carried on in such a way that water is taken only as directed by the Waterworks Superintendent, and so that not more than —— gallons of water shall be required in any one day.

Where the trench is not flooded, it shall be left neatly rounded off on top to a height of twice as many inches as the top width of the trench in feet; and the City may from the 2 per cent reserve make good any settlement below the street surface within one year from the date of completion, notice being first given the Contractor, who may promptly do the work himself if he desires.

All surplus material shall be removed to such point within the limits of the sewer district as may be designated by the City; and in case of deficiency of material, it shall be supplied by the Contractor. The street surface shall be left in neat, sightly condition.

(42) *Foundations.* In case the material encountered should be such as not to be suitable for foundations for the sewer, the Engineer shall direct the character of foundations to be constructed, and this shall be paid for by the City as extra work.

(43) *Protection to Buildings.* The Contractor shall take all necessary precautions to protect building and other structures adjacent to the sewer trenches from injury on account of his work, and shall be responsible for all damages to such structures.

(44) *Existing Sewer and Water Mains.* Wherever existing sewers or water mains are encountered in the work, all necessary precautions shall be taken to prevent injury to them; and in case of an injury, it shall be made good by the Contractor without additional compensation. In case any sewer, drain, or water main should be encountered whose present grade should require changing on account of the new sewers, the work necessary for this shall be performed by the Contractor according to the directions of the Engineer, and shall be paid for as extra work.

(45) *Pipe-Laying.* In pipe-laying, each piece must be set exactly to grade by measuring from the invert to a tightly stretched cord set parallel to the grade line, according to stakes or marks given by the Engineer, and supported at least every 25 feet. In making each joint, a gasket of oakum or hemp freshly dipped in cement grout must first be used and packed into place, so as to make the inverts match exactly, giving a smooth, true flow-line. The joints shall afterwards be tightly packed full and beveled off with 1 to 1 Portland cement mortar; but the cementing must be done at least two pipe lengths behind the pipe-laying. The bell-holes must then be immediately packed with sand to hold the cement in place. Great care must be taken to leave no projecting cement or strings of gaskets on the inside of the sewer, and to make all joints as nearly water-tight as possible. Especial care must be taken in forming the joint on the under side of the pipe.

(46) *House Connections.* At points indicated by the Engineer opposite each lot, and at such other points as may be indicated by the Engineer, 4-inch Y's shall be laid, with the branch tilted up at an angle of about 45°. These shall be furnished and laid without extra charge, up to an average of one in each 25 feet.

At points indicated by the Engineer, deep-cut house connections shall be put in according to the plans. The City shall pay for these the regular contract price.

In both ordinary and deep-cut house connections, the connection shall be closed by a vitrified stopper filled over with sand and lightly cemented.

(47) *Subdrains.* Wherever directed by the City, drain-tile subdrains of diameters directed by the Engineer shall be constructed. Each drain shall be laid just at one side of the sewer, at a depth below the sewer invert equal to the external diameter of the subdrain, *plus* three inches. Each joint shall be wrapped twice with a 4-inch strip of muslin at the time laid. The subdrains shall be laid carefully to line and grade; and wherever the Engineer may direct, 4-inch Y's stopped with brick shall be placed. In general, these Y's will be placed at the same points as the house connections on the sewer.

(48) *Subdrain Outlets.* Wherever directed by the Engineer, subdrain outlets shall be constructed, also as directed by the Engineer, and shall be paid for by the City on the basis of cost as determined by the Engineer, *plus* 10 per cent.

(49) *Measurements.* All measurements of sewers, subdrains, etc., shall be in horizontal lines from center to center of manholes and junctions.

MANHOLES AND OTHER APPURTENANCES

(50) *Manholes.* Manholes shall be constructed as shown on the plans and provided in these specifications, the exact location being indicated by the Engineer. All joints in the brickwork shall be shove joints, being filled full. Especial care shall be taken in forming the channels in the concrete bottoms, and wooden templates or half-sewer-pipe shall be used for this work, as directed by the Engineer. Drop manholes shall be constructed as shown on the plans without additional charge over the price bid, which shall be considered an average price.

(51) *Combined Manholes and Flush-Tanks.* Combined manholes and flush-tanks shall be constructed as shown on the plans and as specified for manholes in clause 50. The siphons shall be carefully set, and the cost of furnishing and setting shall be included in the price bid. The Contractor shall provide and set the water connection and bibbs from a point one foot outside the outside wall, on such side as the Engineer may direct.

(52) *Siphons.* Siphons shall be used as shown on the plans, guaranteed by the manufacturers, and tested after being set before acceptance. For the 8- and 10-inch sewers, 6-inch siphons shall be used, and 8-inch for all sewers larger than 10 inches.

(53) *Lampholes.* Lampholes shall be constructed as shown on the plans and provided in these specifications, the exact locations being indicated by the Engineer. The refilling shall be carefully placed and thoroughly rammed by hand in layers not exceeding 6 inches, around and to a distance of three feet each side of each lamphole. Special pains shall be taken to keep the lampholes truly vertical.

SPECIFICATIONS FOR SEWAGE-DISPOSAL PLANT

(54) *Grading.* All grading shall be done as shown by the plans. The bottom of the filter beds and bottom and sides of the septic tank shall be shaped to true surfaces by hand. All slopes shall be neatly dressed.

Should there be a deficiency of earth for the embankments, the Contractor

may borrow from neatly-shaped borrow pits located on adjacent city land, where directed by the Engineer, leaving a smooth, uniform surface. Should there be surplus material, it shall be deposited along the edge of the lake, as directed by the Engineer.

(55) *Concrete Moulds.* The Contractor shall provide moulds of plank not less than two inches in thickness, thoroughly braced at intervals sufficiently close together to avoid distortion of the moulds. These planks shall be dressed on their edges and on the faces next to the wall. The moulds shall not be removed until the walls have become thoroughly set.

(56) *Facing of Concrete Walls.* In the construction of concrete walls, care shall be taken to keep all pebbles or stones away from the faces of the walls, so that the face shall be smooth and free from cavities or exposed stones or pebbles. The upper surface of the roof shall be floated with 1-2 thin mortar applied when the roof is made, and all cavities in other concrete surfaces filled and smoothed with 1-2 mortar.

(57) *Cement Wash.* On completion of concrete walls and floors, and after removal of the moulds and pointing up defects, all interior surfaces of floors and walls and roof, and the upper surface of the roof, shall be given two good coats of thin, neat Portland cement grout applied with a whitewash brush, time being left between applications for the first coat to set hard.

(58) *Alternating Siphons.* The alternating siphons shall be provided of the make shown on the plans, and set by the Contractor, strictly according to the directions of the manufacturer as given through the Engineer. Any imperfections affecting the working of the siphons when they are tested shall be corrected by the Contractor,who must guarantee their satisfactory working.

(59) *Filters.* The pebbles for the bottoms of the filters shall be screened clean of sand and properly graded, the 2-inch layer of fine pebbles being small enough to hold up the sand placed over it. All sand shall be clean and coarse, but the pebbles need not be screened out. In placing pebbles and sand, care shall be taken not to injure or disturb the drain tile, and the top surface of the sand shall very carefully be made level. Drain tile shall be laid carefully to line and grade.

(60) *Pipe-Laying.* All sewer pipe and cast-iron pipe shall be carefully laid to line and grade, with gaskets and tight joints, all as provided in the regular sewer specifications.

(61) *Sodding.* All earthwork slopes of the tank and filters shall be neatly sodded.

(62) *Bulkheads.* All bulkheads shown on the plans shall be constructed of Portland cement concrete, with moulds, and with care as to facing the same as provided for the concrete work of the septic tank.

(63) *Reinforcing.* The reinforcing shown on the plans is ..... corrugated bars of not less than 50,000 lbs. per sq. in. elastic limit; but other forms of bars having equal elastic limit, equal net area, and a mechanical bond acceptable to the Engineer, may be used. The net area of any bars used must be increased to make good any deficiency in the elastic limit.

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For brick sewers, the following specifications are suggested by Folwell in his book on *Sewerage:*

"For brick masonry in straight walls or sewers, none but whole, sound brick shall be used. For manholes, flush-tanks, and similar work, a limited number of half-brick may be used, not to exceed ¼ of the whole in any case. Unless the Engineer direct otherwise, each brick shall be thoroughly wetted immediately before being laid. It shall be laid with a full, close joint of cement mortar on its bed, ends, and side at one operation. In no case is mortar to be ślushed in afterward. Special care shall be taken to make the face of the brickwork smooth; and all joints on the interior of a sewer shall be carefully struck with the point of a trowel or pointed to the satisfaction of the Engineer. Where pipe-connections enter a sewer or manhole, "bull's-eyes" shall be constructed by laying rowlock courses of brick around them, the cost of such construction being included in the regular price bid for the sewer or appurtenances. Around pipe more than 15 inches in diameter, 2 rowlock courses shall be laid.

"Brickwork in sewers shall be laid by line, each course perfectly straight and parallel to the axis of the sewer. Joints appearing in the sewer shall in no case exceed ¼ inch in width. Sewers shall conform accurately in section and dimensions to the plans of the same. All inverts and bottom curves shall be worked from templates accurately set; the arches are to be formed upon strong centers accurately and solidly set, and the crowns keyed in full joints of mortar. No centers shall be drawn until the arch masonry has set to the satisfaction of the Engineer, and refilling has progressed up to the crown. They shall be drawn with care, so as not to crack or injure the work. The extrados is to be neatly plastered with cement mortar ½ inch thick, the arches being cleaned and wetted just before plastering. The end of each section of brick sewer shall be toothed or racked back; and before beginning the succeeding section, all loose brick at the end shall be removed and the toothing cleaned of mortar. All brickwork shall be thoroughly bonded, adjacent courses breaking joints at least ⅓ the exposed length of the brick.

"If there should be any distortion of the sewer before acceptance, this shall be corrected by tearing down and rebuilding. No local patching will be allowed, but when repairs are necessary a section shall be removed at least 3 feet long and including the entire arch, or the entire sewer if the defect is in the invert. Leakage of ground water into the sewer shall be similarly corrected, unless it can be prevented by calking the joints with oakum saturated in cement, with wooden plugs, or other material acceptable to the Engineer."

FORM OF PROPOSAL

———————————————, ————.

To the Mayor and Council of the Incorporated City of————————, ————.

Gentlemen:

—— have carefully examined the plans and read the specifications prepared for your proposed sewage-disposal plant and sanitary sewers by————, Engineer, and —— agree to furnish all the materials and perform all the labor required for the completion of the proposed work for the following prices:

Item	Approximate Quantity	Unit Price	Total Price
Sewage Disposal Plant, complete			
Sewers, complete, including Y's, except subdrains, manholes, lampholes, and flush-tanks.			
18-inch			
15-inch			
12-inch			
10-inch			
8-inch			
Subdrains, complete			
10-inch			
8-inch			
6-inch			
Deep-Cut House Connections, complete .			
Manholes, complete			
Combined Manholes and Flush-Tanks, complete			
Lumber Left in Trenches (per M., B. M.)			

All the above shall be strictly in accordance with the plans and specifications.

In case ——bid is accepted,——agree to begin work within three weeks after the acceptance of —— bid, and to entirely complete the work on or before————————————,————.

————— further agree to enter into contract and furnish bond satisfactory to the City Council within 12 days after acceptance of —— bid.

Respectfully submitted,

————————————

————————————

94. Form for Sewerage Contract. Besides plans and specifications, the sewerage Engineer is sometimes called upon to furnish a *Form of Contract* to be signed by the Contractor and the city representatives, though this, more properly, should be the work of the City Attorney. The following simple form of contract has been used successfully with specifications such as those given above:

This Article of Agreement, made this ———— day of ———————— A.D., ——, by and between ————————, of ————————, ————, party of the first part, and the Incorporated City of ————, ————, acting through its Mayor and Council, party of the second part,

WITNESSETH:

The party of the first part agrees to furnish all material and perform all labor required for the entire completion of sanitary sewers, subdrains, and other appurtenances, on streets in the said City of ————, ————, as follows:

(NOTE: In this space place a list of the sewers included in the contracts by streets, giving the sizes on each street of both sewer and subdrain, and the points at which each size begins and ends.)

All the above sewers are to have manholes and other appurtenances as shown by the plans and specifications.

The party of the first part further agrees that all the above labor and materials shall be strictly in accordance with the sewer plans and specifications prepared for the party of the second part by ————————, Engineer, said plans and specifications identified by the signatures of the parties hereto, being hereby made a part of this contract.

The party of the second part agrees to pay to the party of the first part for the above labor and materials, the following prices:

Sewers, complete, except subdrains, manholes, lampholes, and flush-tanks,		
24-inch	$	per lin. ft.
20 "		" "
18 "		" "
15 "		" "
12 "		" "
10 "		" "
8 "		" "
Subdrains, complete,		
24-inch		" "
18 "		" "
15 "		" "
12 "		" "
10 "		" "
8 "		" "
Manholes, complete	$	each
Lampholes, complete		"
Combined Manholes and Flush-Tanks, complete		"
Flush-Tanks, complete		"
Lumber ordered left in trenches	$	per M., B. M.

The payments shall be made in————————————————————

————————————————————and paid to the party of the first part in accordance with the provisions of the specifications, 2 per cent being reserved for one year to guarantee the work.

IN WITNESS WHEREOF we have hereunto set our hands and seals the date and place first above mentioned.

————————————————————

Party of the First Part

SEAL

The Incorporated City of ————, by

————————————————————Mayor,

SEAL

————————————————————

Party of the Second Part

95. Form of Bond for Sewerage Contract. The Contractor for a piece of sewerage work is usually required to furnish to the City a bond, which is frequently for a sum equal to about one-half the

amount of the contract. The simpler the form of the bond, the better. The following form has been used successfully:

BOND

KNOW ALL MEN BY THESE PRESENTS, that we,————————, of ————————, ———, Principal, and

———————————————————————————

———————————————————————————

———————————————————————————

Sureties

are held and firmly bound to the Incorporated City of ————, ————, in the penal sum of ———————— Dollars (————), lawful money of the United States of America.

NOW, THE CONDITION OF THIS OBLIGATION is that whereas the above-mentioned ————————, of ————————, ——, has entered into contract with the Incorporated City of ———, ——, dated ———., A. D. ——, to furnish all labor and materials required for the entire completion of about ——— feet of sanitary sewers, subdrains, and other appurtenances for the said City of ————, ————, now, if the said ————————, shall well and truly perform all the obligations of his said contract, strictly according to the terms thereof, then shall this bond be null and void, but otherwise it shall be and remain in full force and effect.

———————————————

Principal

———————————————

———————————————

Sureties

CONSTRUCTION OF SEWERS

96. Letting the Sewer Contract. After the plans and specifications have been completed and accepted by the City, the next step will be to let the contract for the work.

First. The work should be advertised, if possible, three or four weeks in advance, in at least two good engineering or trade journals. It must often, by law, be advertised also in at least one local journal. For a form for the advertisement see pages 112 and 113.

Second. On the day and at the hour specified in the advertisements, the City Council meets to open the sealed bids which have been submitted on the blank "forms for proposals" furnished by the City for the purpose.

Third. If the bids are satisfactory, the contract is awarded to the *lowest responsible bidder.*

Fourth. A contract for executing the work in accordance with the plans and specifications, is signed by the Contractor and by the City.

Fifth. The Contractor furnishes a bond satisfactory to the City.

In all these steps, there is need of great care on the part of the city authorities to make sure that all provisions of the law are com-

plied with, and they should be fully advised at all times by a competent attorney.

97. Organization of Engineering Force during Construction of Sewers. It is not common for the Consulting Engineer who prepares the sewerage plans and specifications, to be constantly on the ground or even in the city during construction. He makes only occasional visits for inspection and consultation.

The actual work of sewer construction is usually directly supervised either by the City Engineer, or by a *Resident Engineer* employed especially for this purpose.

It will be necessary for the resident engineer in charge of the construction of a sewerage system of some magnitude, to have an office and an adequate equipment of drafting apparatus, surveying instruments, etc. He will have employed under him:

Draftsmen and clerks, in the office.
Instrument men and rodmen, to do the surveying.
Inspectors, constantly on all work, to insure its being properly executed.

The resident engineer himself will supervise these employees, visit all parts of the work frequently, and constantly exercise general supervision over all its features.

98. Laying Out the Sewer Work. After checking up the bench-marks on the original survey, it will be necessary for the engineering force to stake out the sewers, keeping somewhat in advance of the actual construction.

The stakes are usually placed a uniform distance to one side of the true line, so as not to be disturbed by the digging of the trench. This distance, and the side on which the stakes are placed, should be the same for all parts of the work, to avoid confusion and mistakes.

The stakes should usually be set about 25 feet apart.

The manholes should usually be located first, in accordance with the profile sheets; and the sewers should be run as straight lines, center to center of adjacent manholes. All discrepancies from the original measurements should each be adjusted, if possible, between the two manholes between which each was found; and such discrepancies should not be carried on to affect all the rest of the work.

There are two methods of giving grades for sewers.

(1) The best method is to set the grade stakes nearly flush with the surface, at a uniform offset to one side of the trench, ascertaining

the distance of the top of each stake above grade by carefully checked levels. By measuring from these stakes, a grade cord, supported on cross-frames every 25 feet, is stretched parallel to the grade line of the sewer, over its center line. For this method of giving grades, see Fig. 40.

(2) Another method is to set grade stakes at the bottom of the trench. This method is adapted only to very large sewers.

99. Trenching and Refilling. Sewer trenching and refilling may be done either by machines or by hand. *Excavating Machines* for sewers are of two types:

(1) *Machines which themselves do the excavating.* These are just coming into use, and are becoming more and more successful.

(2) *Machines which simply carry away the excavated material,* usually dumping it over the completed sewer further back. This type has the advantage of not piling up the dirt in the busy street. It carries, on overhead cableways or trestles, buckets which can be lowered into the trench, and in which the excavated material is placed by hand.

Machines of both types are suited best to comparatively extensive work; and under favorable conditions they lessen the cost materially.

Most sewer trenching, however, is done by *hand.* For such work the men are organized in gangs, the number of men in each gang varying from 20 to 80. Each gang has a foreman, and a water boy, and sometimes a sub-foreman. A pair of pipe-layers may work with each gang, or, if the trench be deep, one pair of pipe-layers may work part of the time with one gang and part with another.

The details of sewer trenching and refilling as ordinarily carried out, are specified quite fully in clauses 38, 40, and 41 of the sample sewer specifications given in Art. 93 (which clauses now read carefully). All details there specified should be enforced by the Inspector and the Engineer.

In clause 41, Art. 93, referred to above, the method specified for compacting the refilling is by flooding with water. While this is the cheapest method, where the water is available, and while it gives good results if properly done, it may be found necessary sometimes, in the case of paved streets, to adopt the more expensive method of *tamping.* For thorough tamping, there should be from 1 to 2 men tamping, to 1 shoveler, and the rammers used should weigh 4 to 6

pounds each. The soil refilled should be moistened if dry, and should be tamped in about 4-inch layers. It is possible by very thorough tamping to compact the soil more thoroughly than by flooding.

100. Sheathing. Except for shallow ditches in very solid earth, it is usually necessary to brace the sides of sewer trenches to prevent their caving in. Such bracing is called *sheathing*. The most common methods of sheathing are illustrated in Fig. 40.

The horizontal members of the sheathing are called *rangers*, and the rangers are held the right distances apart by *sewer braces* of wood or iron. The iron braces are shown in Fig. 40. The rangers are usually about 12 feet long. Behind the rangers are placed the vertical planks of the sheathing, either a few feet apart in firm material, forming *skeleton sheathing*, or in contact with each other in caving material, forming *close sheathing*. The sheathing plank are 2 inches thick and are usually about 10 feet or 12 feet long. The rangers may be 2-inch planks in favorable soil, or 4 by 4 or even 4 by 6 inches in poor soil.

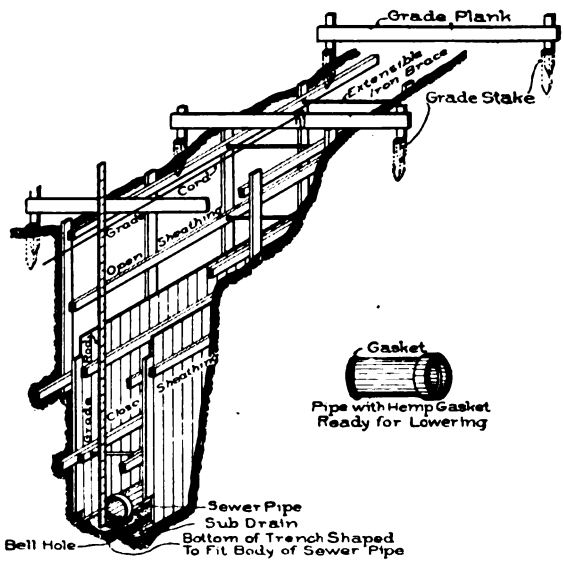


Fig. 40. Diagram Showing Construction of Pipe Sewer.

The sheathing plank are usually driven by hand, with wooden mauls.

Sometimes, for large sewers, heavy *sheet piling* may be driven by pile-drivers, to take the place of ordinary sheathing.

Ordinary sheathing is removed from the trench as the refilling proceeds. In case of special danger to near-by water mains, conduits, or foundations, on account of possibility of the banks caving before the refilling is finally settled, the Engineer may order the sheathing

to be left permanently in the trench. In such case, the Inspector makes record of the exact amount of lumber left in the trench, and the City pays for it.

101. Pipe-Laying. The pipe-laying is usually done by two men, though, with large pipes, another may be needed. These men excavate the last few inches of the trench, as well as lay the pipes.

The laying of every pipe, and the making of every joint, should be carefully watched by an Inspector, who should faithfully enforce the specifications.

For specifications for pipe-laying, see clause 45, Art. 93 (which clause now read carefully).

All the sewer pipe should be carefully inspected before being used, and those pieces rejected which do not meet the specifications. See clause 25, Art. 93. The Inspector should see that no rejected or poor pipe is used.

The Inspector should see that every pipe is laid exactly to grade by measurement from the grade cord (see Fig. 40).

The Inspector should also see that house-connection Y's are placed opposite each lot on each side of the street, at the proper points; and he must exactly locate each such connection by measurements fully recorded in his notebook.

102. Construction of Brick Sewers. For specifications for the construction of brick sewers, see reference to Folwell in Art. 93, p. 122. (Read carefully.)

The construction of a brick sewer is shown in Fig. 41.

It will be the duty of the Inspector to inspect all brick before they are used, rejecting the poor ones, and to fully enforce the specifications for construction. He must also see that the templates are set truly to line and grade, that the house connections are set at the proper places and heights, and accurately located in his records.

In the case of large brick sewers, more trouble is to be expected with foundations than in the case of pipe sewers. Sometimes soft soil or quicksand may make it almost impossible to shape the material in the bottom to fit the outside of circular sewers. In such cases, special foundations, such as shown in Fig. 20, may have to be put in through the treacherous material. Other forms of special foundations are often used.

The Engineer should make full record of all such features of the work.

103. Records of Sewer Construction. *Daily Reports.* The resident Engineer in charge of the construction of a sewerage system, should require, from all members of his engineering force, daily reports, on suitable blank forms, showing the exact work on which each was engaged. Another set of exact reports should show the work accomplished by the Contractor each day, and the materials and labor used on each part of the work.

Data of Sewer Construction. The information from these daily reports should be entered in a permanent book, showing all features

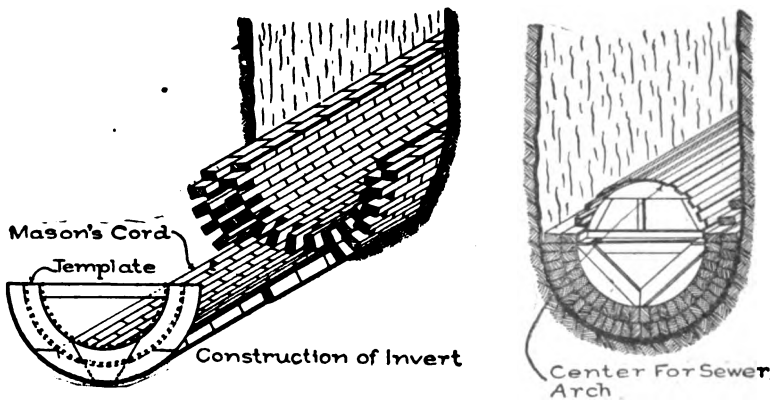


Fig. 41. Diagrams Showing Construction of Brick Sewer.

of the progress of the work, and giving data for itemized estimates of the cost.

Sewer Record Book. In another permanent book, a complete, final record of all the sewers should be entered.

On the left-hand page may be given in order the numbers of the stations of the sewer survey, running from the bottom to the top of the page, together with the surface elevations, the grade elevations, and the rate of grade.

The exact character of the soil should also be shown, with exact levels for computing any rock excavation. Notes should be made of the level and amount of any ground water encountered.

On the right-hand page should be made a large-scale sketch of the sewer, showing its exact location with reference to the street lines

and the lot lines, and the exact location of manholes and other accessories. This sketch should also show the location of all house connections, with exact measurements (such as the station and *plus* of each connection) by which to locate all such connections.

On the right-hand page may also be entered the exact limits of sheathing left in trenches, and the amounts of lumber in such sheathing, as well as the exact limits and character of all special sewer

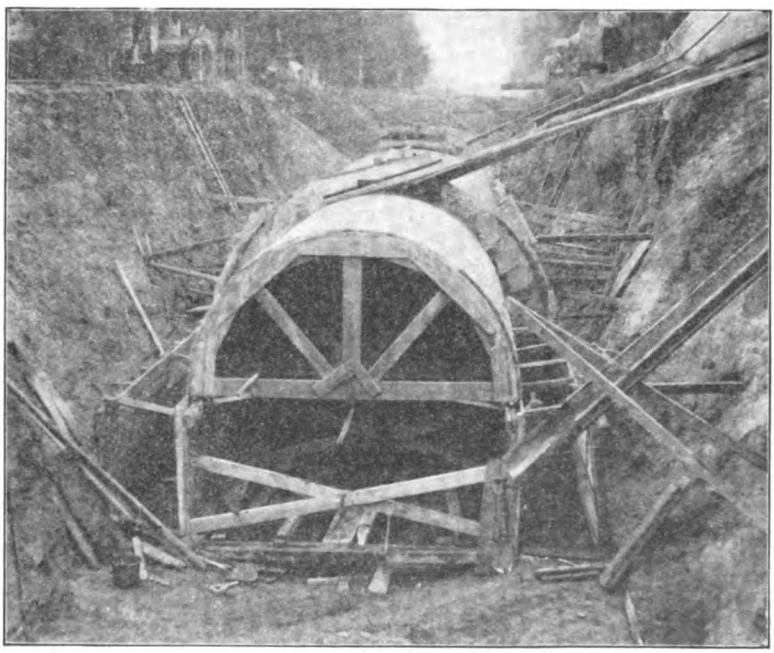


Fig. 42. Construction of Dry-Run Concrete Sewer, Waterloo, Iowa.

foundations, of changes of grade where other conduits are crossed, and of all other extra work.

Final Sewerage Map and Profiles. On completion of the system, the resident Engineer should make a complete final sewerage map, and complete final profiles of all sewers, both corrected by any changes from the original plans adopted during construction.

Plat of Sewer Connections. For small towns, at least, large-scale plats of the different streets should be prepared, showing the exact location of all house connections.

MAINTENANCE OF SEWERS

104. Sewerage Systems should be Carefully Maintained in Good Condition. Too often it appears to be considered that when a sewerage system is completed all further care of it can be neglected with impunity. This is a great mistake. The sewerage system may become a source of danger to the public health, instead of a means of safety, unless it is given proper care and attention.

105. Sewer Ordinances, Permits, and Records. Every city having sewers should pass a carefully prepared *Sewer Ordinance*, prescribing in detail the conditions under which citizens are permitted to use the sewers.

One provision of the Sewer Ordinance should be, that all property owners desiring to make sewer connections shall first secure a *Sewer Permit*. For this and for the application for it, blank forms are provided, which are to be filled in by the applicant, giving full description of the connection. The permit will require the work to be done according to the city regulations.

Every house sewer should be connected with the sewer at a regular house connection. No cutting into the sewer whatever should be permitted, as there is great danger of such cutting ruining the sewer.

Full *Sewer Records* should be kept by the proper city officers, showing full details of all connections with the sewers. This is too often neglected, to the great detriment of the City, which finds itself without means of ascertaining what people or how many are using the sewers, and perhaps putting injurious substances into them.

106. Plumbing Regulations, Tests, and Licenses. The city should also prescribe by ordinance strict *Plumbing Regulations*, setting forth in full detail the requirements for good plumbing (see Articles 76 to 81 inclusive). All property owners should be required to do all plumbing in strict accordance with these regulations.

The work should be carefully *inspected and tested* by a City Inspector, to see that it fully complies with the ordinance. The *water test* is applied by stopping up the outlets of the soil-pipe and of the various fixtures, and filling the pipes with water, when defects will be shown by leaks. In the *smoke test*, the pipes are blown full of smoke; and in the *peppermint test*, oil of peppermint is poured into them. In neither case must it be possible to detect any of the odor in the interior of the house.

Plumbing regulations usually require that plumbing shall be done only by plumbers holding *plumbers' licenses* granted by the City. The proper city officers have blank forms for making applications for such licenses, as well as for the licenses themselves. The plumber making application for a license should be required to show proof of proficiency, and should be placed under bond to comply fully with the sewer ordinance and the plumbing regulations, and to protect the City from damages on account of his work. The plumber may also be made subject to fines for violating the sewer ordinance and regulations, and to revocation of his license.

107. Regular Sewer Inspection. In sewer maintenance, besides the work of granting sewer permits, and inspecting house plumbing and the making of connections with the sewers, the entire sewerage system should be gone over regularly and carefully by a Sewer Inspector, once every two weeks if possible.

The Inspector, in this work, should open all manholes and lampholes, and carefully examine the sewer to make sure that it is keeping clean, well-ventilated, and reasonably free from offensive odors. He should also examine carefully the working of all flush-tanks, to make sure that they are operating satisfactorily. He should also examine all catch-basins, to make sure that they are cleaned frequently enough.

Small defects found on these periodical inspections should be remedied at once, and full notes made of more extensive work found to be necessary.

108. Flushing and Cleaning of Sewers. In many sewerage systems, it is found impossible to prevent absolutely the formation of deposits in the sewers, which must then be removed by hand-flushing, or by direct cleaning of the sewers.

Flushing is ordinarily preferred to hand-cleaning methods where the water for the purpose is available, and where it is readily possible to remove the deposits in this way. For the most common methods of hand-flushing, see Art. 25.

In hand-cleaning, large sewers may be entered by the workmen themselves to remove the deposits. In small sewers, lines are often floated down from one manhole to the next below; and by means of these lines, various cleaning devices are dragged through the sewer, or back and forth in it, to remove the deposits. Sometimes, for small

sewers, a ball, a little smaller than the sewer, with a line attached to haul it back in case of stoppage, is allowed to float down the sewer, from manhole to manhole. The sewage is dammed back by it, and spurts out on all sides under pressure, thus scouring and cleaning the sewer.

For large sewers, discs or gates, traveling on carriages, or boats, may be used, working on the same principle. Many forms of such apparatus have been devised. A notable example of the use on a large scale of traveling sewage-scouring gates is in connection with the Paris sewers, Fig. 24.

109. Cleaning of Catch-Basins. In Art. 27, catch-basins were described; and it was stated that unless they are frequently cleaned they become filled with filth and soil and debris from the street, and fail utterly in their purpose, which is to keep such materials out of the sewers. Moreover—which is still worse than this—uncleaned catch-basins are unsanitary, and are sources of foul odors. Hence catch-basins, when used, should be regularly cleaned, and the City should have a regular arrangement for this work, and should provide labor-saving apparatus for the work, such as hoisting apparatus or special pumps for lifting the material from the catch-basins to the wagons.

SEWAGE DISPOSAL

110. Sewage Disposal Definitions. There is some confusion as to the meaning which should be given to the term *sewage disposal*, there being a tendency to treat it as meaning the same thing as sewage purification. It seems wise to hold more closely to the strict meaning of the words.

Sewage Disposal refers to the means adopted for disposing of, or getting rid of, sewage.

Sewage Purification is treatment of sewage to rid it of its foul impurities and render it harmless.

111. History of Sewage Disposal. In ancient times the only method used for disposing of the sewage of cities was to empty it into some stream or other body of water. This method, called *dilution*, is still in use more than any other, owing to its cheapness. From time immemorial, however, the cesspool has been used to receive the sewage of private houses, and we now know that a considerable

percentage of purification is effected in cesspools, by bacterial action of the same nature as that now utilized in the modern *septic tank.*

By the middle of the nineteenth century the construction of sewerage systems had increased to such an extent that the streams in thickly settled countries became badly polluted by sewage, and it became necessary to turn attention to methods of purification. In England, especially, much work was done, and much success was attained with purification by *land treatment*, or *irrigation.* A great deal of work was done, also, in the same country, with methods of *chemical treatment.*

In 1887, the Massachusetts State Board of Health in this country began extensive experiments in sewage disposal, which soon demonstrated the great value of *intermittent sand filtration.*

About 1896 the *septic tank* came into prominence in both England and the United States. At about the same time, also, the *contact bed* was developed in England, and soon after copied in the United States, where it did not prove much of a success.

Within the last few years, *sprinkling filters* have come into use for conditions which require a large amount of sewage to be purified on a small area.

There is, at present, much activity in sewage purification, both as regards actual construction of plants, and as regards continued experimentation and research.

112. Importance of Sewage Disposal. The importance of sewage disposal at the present time is very great. All cities and nearly all villages find sewers indispensable, yet neither law nor justice will permit them to cause damage to the property or danger to the health of other communities or persons by discharging in their midst foul, unpurified sewage. More and more sewage purification plants are being required in connection with sewerage systems. Communities which disregard the rights of others in this respect are more and more finding that they must face damage and injunction suits.

113. Variable Composition of Sewage. Prior to taking up methods of sewage purification, it will be necessary to learn something about the composition of sewage; and the first thing to be noted is that the composition is extremely variable. Even in the same sewer, sanitary sewage is much stronger in the daytime, when the flow is heavy, than at night, when the flow is light. In fact, the composition

will vary from minute to minute. Manufacturing and storm sewage, also, vary greatly in character at different places and times.

A sample of sewage for analysis, therefore, should consist of a mixture of several small amounts, taken systematically at different times, with great care to get a truly average portion each time.

114. Chemical Analyses of Sewage. Chemical analyses of sewage are *indirect*—that is, it is impossible to determine *directly* the amount and kind of polluting organic matter. Hence the chemist determines a number of things, harmless in themselves, from which he can judge in a general way of the amount and kind of the polluting organic matter. The things usually determined in a chemical analysis, and their meanings, are as follows:

Chlorine. This is in the form of common salt, in itself harmless. In sewage it indicates the strength of the original sewage, but not whether or not it has been purified.

Albuminoid Ammonia. This indicates the amount of undecayed organic matter, containing nitrogen, in the sewage.

Free Ammonia. This indicates the amount of decaying organic matter, containing nitrogen, in the sewage.

Nitrites. These indicate a further step in the process of decay (which is also the process of purification).

Nitrates. These indicate purified organic matter, containing nitrogen.

Oxygen Consumed. This gives an indication of the total unoxidized organic matter in the sewage.

Solids on Evaporation. These indicate the total foreign matter in the sewage, whether organic and therefore dangerous, or mineral and therefore probably not dangerous.

Loss on Ignition. This is intended to indicate the total organic matter which can be burned out of the solids on evaporation by heating them to a red heat; but if the water has a high mineral content, the loss on ignition does not appear to give a very reliable indication of the organic matter.

115. Bacterial Analyses. Bacterial analyses of sewage, as usually made, are quite simple, consisting simply of determinations of the total number of bacteria, without regard to their different kinds, in one cubic centimeter of the sewage. Most of these bacteria are

perfectly harmless; but where many bacteria can flourish, disease germs might at any time flourish also.

116. Sample Analyses of Sewage. In Table XIV are presented a few random samples of chemical and bacterial analyses of sewage from sewage purification plants.

The sewage analyzed at Fort Des Moines was weak; that at Ames, stronger, but hardly of average strength; and that at Mt. Pleasant, of about average strength.

For each place, the *raw sewage* represents the *unpurified* condition; the *septic tank effluent*, the *partially purified* condition; and the *filter effluent*, the *purified condition* of the sewage. The purification at Fort Des Moines and at Ames was very good, and that at Mt. Pleasant poor.

TABLE XIV

Sample Analyses of Sewage from Purification Plants

Parts per 1,000,000

Place and Kind of Sewage	Chlorine	Albuminoid Ammonia	Free Ammonia	Nitrites	Nitrates	Oxygen Consumed	Solids on Evap.	Loss on Ignition	Bacteria per Cu. C. M.
Ft. Des Moines, Ia.									
Raw Sewage	16.0	6.0	2.5	Trace	0	20.6	490	130	713,000
Tank Effluent	18.0	6.5	8.5	0	0	15.9	524	166	582,000
Filter "	16.0	0.4	0.5	Trace	12.0	6.3	460	120	1,100
Ames, Iowa.									
Raw Sewage	60.0	7.5	20.0	0	0	96.2	950	230	495,000
Tank Effluent	61.0	5.0	21.0	0	0	99.6	978	226	849,000
Filter "	80.0	0.6	0.1	Trace	4.8	20.2	1,150	250	900
Insane Asylum Mt. Pleasant, Ia.									
Raw Sewage	150.0	5.0	28.0	0	0	64.6	2,412	440	1,680,000
Tank Effluent	157.0	4.0	28.5	0	0	105.0	2,072	278	1,210,000
Filter "	150.0	4.0	16.0	Trace	0	25.3	2,062	270	519,000

117. Methods of Sewage Purification. The principal different methods of sewage purification are as follows:

Irrigation. In this method, the sewage is used to irrigate crops, on a *sewage farm.* The method is very efficient with sufficiently porous land; but the large area required, and the difficulty experienced by cities in successfully operating sewage farms, restrict the use of this method in the United States almost entirely to the arid regions, where the soil requires irrigation anyhow, and where water for irrigation is scarce and valuable. The method is also used to a consider-

able extent in Europe, notably in Paris, in Berlin, and in Birmingham and several other English cities.

From 5,000 to 25,000 gallons of sewage per acre per day may be purified by irrigation, depending upon the porosity of the soil. Porous, sandy soils are the best. A very high degree of purification can be attained by irrigation.

Chemical Precipitation. In this method, certain chemicals (usually lime, alum, or iron) are added to the sewage, to precipitate the suspended organic matter, in *precipitation tanks.*

On account of the great cost of the chemicals and labor required, and the great difficulty of satisfactorily disposing of the large amount of *sludge* precipitated, the chemical treatment of sewage is now very seldom adopted, though it was quite popular twenty-five years ago. Only 25 to 50 per cent efficiency can be attained.

Settling Tanks. These are for a preliminary treatment, sometimes given sewage before filtering it, in order to get rid of part of the solid matter in the sewage, which otherwise might tend to clog the filters. Some bacterial purification also occurs in settling tanks.

Septic Tanks. These tanks are larger than settling tanks, and hold the sewage and sludge (or solid matter settling in the tank) long enough for bacteria to act and to effect partial purification. This is also, usually, a treatment preliminary to filtration. For further discussion, see Art. 120.

Intermittent Sand Filtration. In this method the sewage is discharged *intermittently,* upon the surface of sand filters. The sewage may or may not have first a preliminary treatment in tanks. This is a very efficient method, and is one of the most common at present in use. For further discussion, see Art. 122.

Contact Beds. These are filters of coarse material (say $\frac{1}{8}$-inch to one-inch size) with water-tight walls and bottoms, which are alternately filled with sewage, allowed to stand full for a certain *contact period,* emptied, and allowed to stand empty for a certain *aëration period.* This method was quite popular a few years ago, but proved inefficient and troublesome in many places, and is now largely out of favor.

Sprinkling Filters. These filters, also, are made of coarse material; but the sewage is *sprinkled* continuously upon the surface, so as to trickle slowly over the pieces of filter material, the outlet

drains being left open all the time. This method has lately come into favor as requiring much less area than sand filters, though not so efficient, and is now the method commonly recommended where circumstances render it advisable to adopt high rates of filtration, though at some cost of efficiency. For further discussion, see Art. 123.

118. Methods of Sewage Disposal Now Most Commonly Used. These are:

(*a*) *Dilution*, where purification is not required.

Where, on the other hand, purification is required, the usual methods are:

Preliminary Treatment by
(*b*) *Septic Tanks*, or by
(*c*) *Settling Tanks*,
followed by
Final Treatment by
(*d*) *Intermittent Sand Filters*, or by
(*e*) *Sprinkling Filters*.

119. Dilution. In this method of sewage disposal, the sewage is simply discharged into the ocean, or into a lake, a river, or other body of water, dilution by the water being relied upon to prevent the creation of a nuisance by the sewage. In the water, bacterial processes of purification by decay start up, which, after a sufficient time, break up the organic compounds in the sewage, and finally render it harmless.

Dilution has, over other methods, the one advantage of *cheapness;* and this is still sufficient to decide in its favor in the majority of cases, when the body or stream of water utilized is sufficiently large to prevent a nuisance. Chicago furnishes a most notable example of large expenditure to secure sufficient dilution for its sewage, having already expended over $50,000,000 in building the great "Drainage Canal" (see Fig. 5) to take water from Lake Michigan for this purpose.

Most cities in the United States dispose of their sewage by dilution, and the sewerage Engineer should always give the possibilities along this line full consideration. He will usually advise adoption of the method (at least for the present) where it is cheaper, and where it is certain that a nuisance will not be created, nor serious damage or danger to other communities or persons result.

120. Septic Tanks. These are simply large tanks, in which the sewage is held long enough for most of the solid matter to settle

out, and long enough for certain species of bacteria to act both upon the liquid sewage and the sludge.

Theory of Action of Septic Tanks. The bacteria which flourish in septic tanks belong to the general class known as *anaërobic* bacteria. This term means bacteria which do not need the oxygen of the air to live. In ordinary decay of organic matter, anywhere, both these and other bacteria are the active agents, and some of the germs are found in all sewage. In septic tanks the conditions are favorable to the enormous development of anaërobic bacteria, since the sewage is still, and there is usually no free oxygen in the sewage, and since, moreover, there is abundance of the organic matter which forms the food of these particular bacteria. In septic tanks, the bacteria act upon the sludge, to partially liquefy it; and they also act upon the organic matter in both the solid and the liquid state, to partially purify it.

Efficiency of Septic Tanks. In practice it is found that septic tanks remove only 25 to 50 per cent of the organic matter in the sewage, and that the bacteria in the effluent are very high in number (see Table 14).

Essentials of Septic Tanks. The only essentials of septic tanks are: (1) That the sewage shall be introduced and taken out in such a way as to insure a uniform distribution through the entire cross-section as it passes through the tank; (2) that the outlet shall be so arranged that neither the floating scum on top nor the layer of settled impurities at the bottom shall be permitted to escape; (3) that the tank shall be large enough to hold the sewage sufficiently long for the bacterial action, but not so long that the bacterial action proceeds too far, which might cause excessive offensive odor, and unfit the sewage for filtration. A capacity of 12 to 24 hours' flow of sewage is usually considered to be the proper size.

Septic tanks are commonly used preliminary to filtration of the sewage.

In Fig. 43 is shown the general arrangement of a typical sewage-disposal plant for a small city. It consists: (*a*) of a *septic tank* of 80,000 gallons' capacity, in which the sewage is first received; (*b*) of *two sand filters*, each containing 13,000 sq. ft. of area, through which the sewage is filtered after first passing through the septic tank; and (*c*) of a *sludge area* provided for drying the sludge after it is taken from the septic tank, preparatory to hauling it away.

Usually *a septic tank should be nearly emptied of sludge about once a year.* The sludge area may be simply a prepared earth area, on which the sludge can stand and drain. Usually the sludge area is at a lower elevation than the bottom of the septic tank, and the sludge

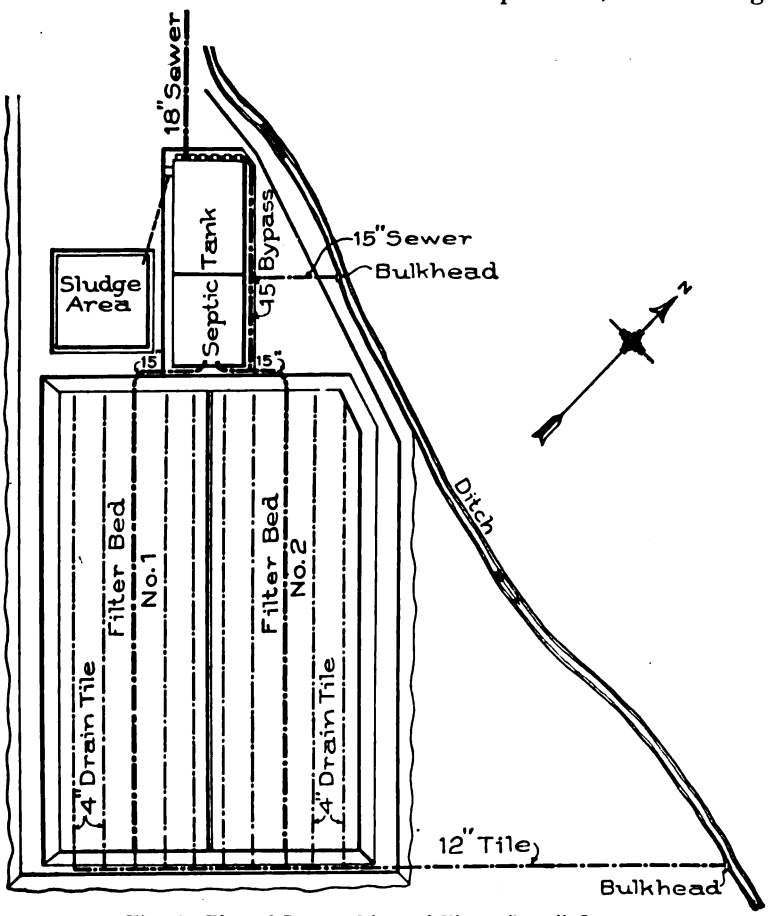


Fig. 43. Plan of Sewage-Disposal Plant, Carroll, Iowa.
Original Scale, 1 Inch = 40 Feet.

is allowed to run out upon it through an iron pipe, by gravity. Otherwise a centrifugal pump may be provided for pumping out the tank.

In Fig. 44 detailed plans are given of the septic tank whose general location is shown in Fig. 43. The tank shown is made entirely of concrete, reinforced with steel rods. Even the flat roof is 5 inches of reinforced concrete. It consists of two parts as shown, a *septic tank proper,* and a *dosing chamber.*

The *septic tank proper* holds 60,000 gallons, and is divided longitudinally into two compartments, one twice as large as the other, to permit the size used to be varied to suit the amount of sewage flowing. Entering at the left-hand end of the tank, as shown in Fig. 44, the sewage passes into the tank through 6 openings, and, striking a baffle wall, the currents are forced down and spread out to give a uniform distribution of the flow. At the opposite end of the septic tank proper, the sewage must pass up under another baffle wall, and then flows into the dosing chamber over six weirs, opposite the six inlets. In falling from the weirs the sewage is aërated.

The *dosing chamber* holds 20,000 gallons, and is provided with two *alternating siphons*, one connected with each sand filter bed.

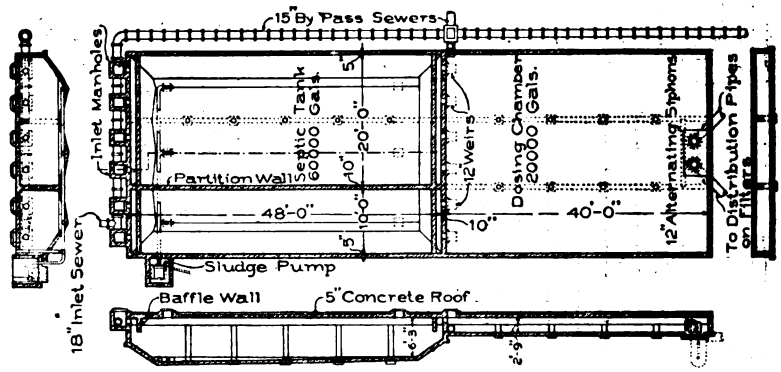


Fig. 44. Plan and Sectional Elevation of Septic Tank, Carroll, Iowa. Original Scale, ¼-Inch = 1 Foot.

These are similar to the flushing siphons described in Art. 24, but are so arranged that they discharge in rotation. Whenever the dosing chamber fills to the high-water line, one of these siphons discharges the entire 20,000 gallons within a few minutes upon the surface of its filter. The distribution of the sewage upon the filters is thus automatic. There are other types of automatic distributing apparatus. Those having moving parts are more liable to get out of order than are siphons.

In Fig. 45 is given a view of the above concrete septic tank during construction.

Many other designs of septic tanks are used successfully. In some, a house is built over the sewage.

In Fig. 46 is given an interior view of the dosing chamber of

one of the septic tanks at Ames, Iowa. The alternating siphons appear in the view.

121. Settling Tanks. Settling tanks differ in no essential way from septic tanks, except in point of size. Settling tanks are made much smaller than septic tanks, and hence do not afford time for so complete bacterial action, and must be emptied of sludge frequently, instead of only once a year. Hence a complete, convenient, and inexpensive means of cleaning out and drying the sludge is even more important than in the case of septic tanks.

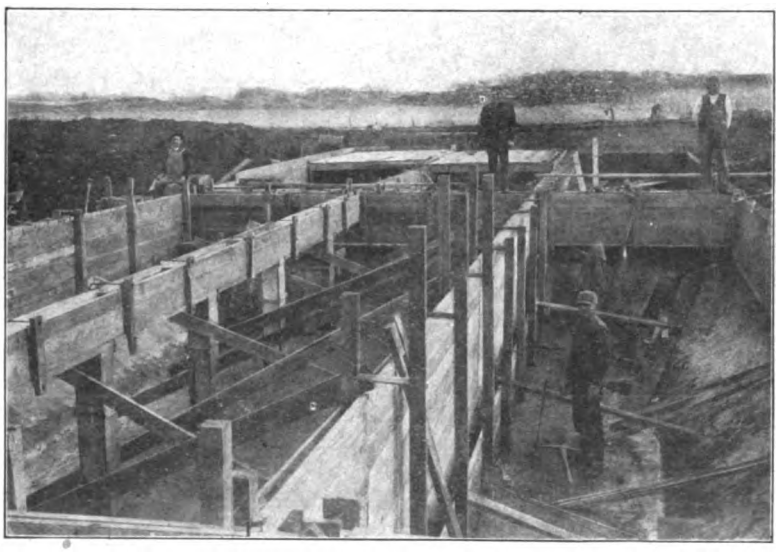


Fig. 45. Septic Tank at Carroll, Iowa, under Construction.

122. Intermittent Sand Filters. With the exception of irrigation under favorable conditions, intermittent sand filtration furnishes the most efficient means of purifying sewage which is in common use. In this method, the sewage is discharged *intermittently* upon the surface of sand filters 2½ to 4 feet deep. The area of filter needed will usually be one acre to every 100,000 to 150,000 gallons of sewage per day. Any good, clean, coarse mortar sand will answer for the filter. The filter is usually underdrained by lines of agricultural drain-tile placed 5 feet to 20 feet apart; and the bottom of the bed is often covered with a layer of graded pebbles or broken stone, to make the drainage more nearly perfect.

Theory of Action of Sand Filters. In each cubic foot of sand are many millions of particles of sand, whose aggregate surfaces may amount to thousands of square feet, and these particles have many millions of intervening pores. Upon the surfaces of the sand grains, the bacteria of purification become established in innumerable billions,

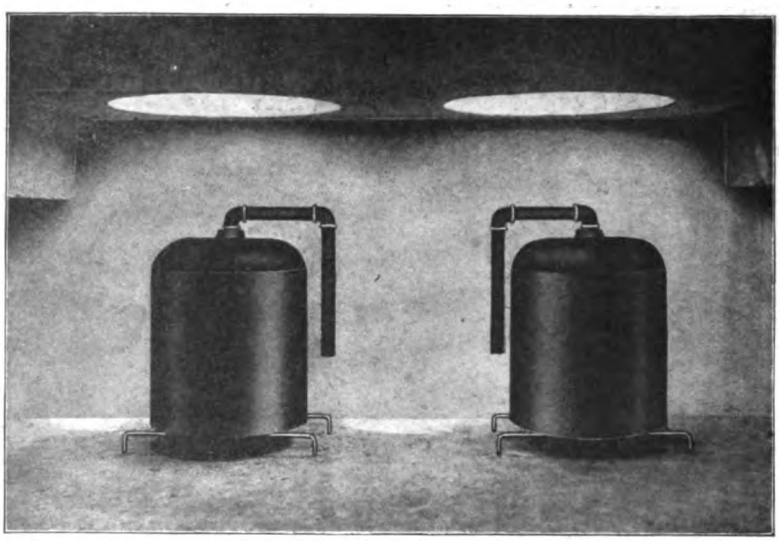


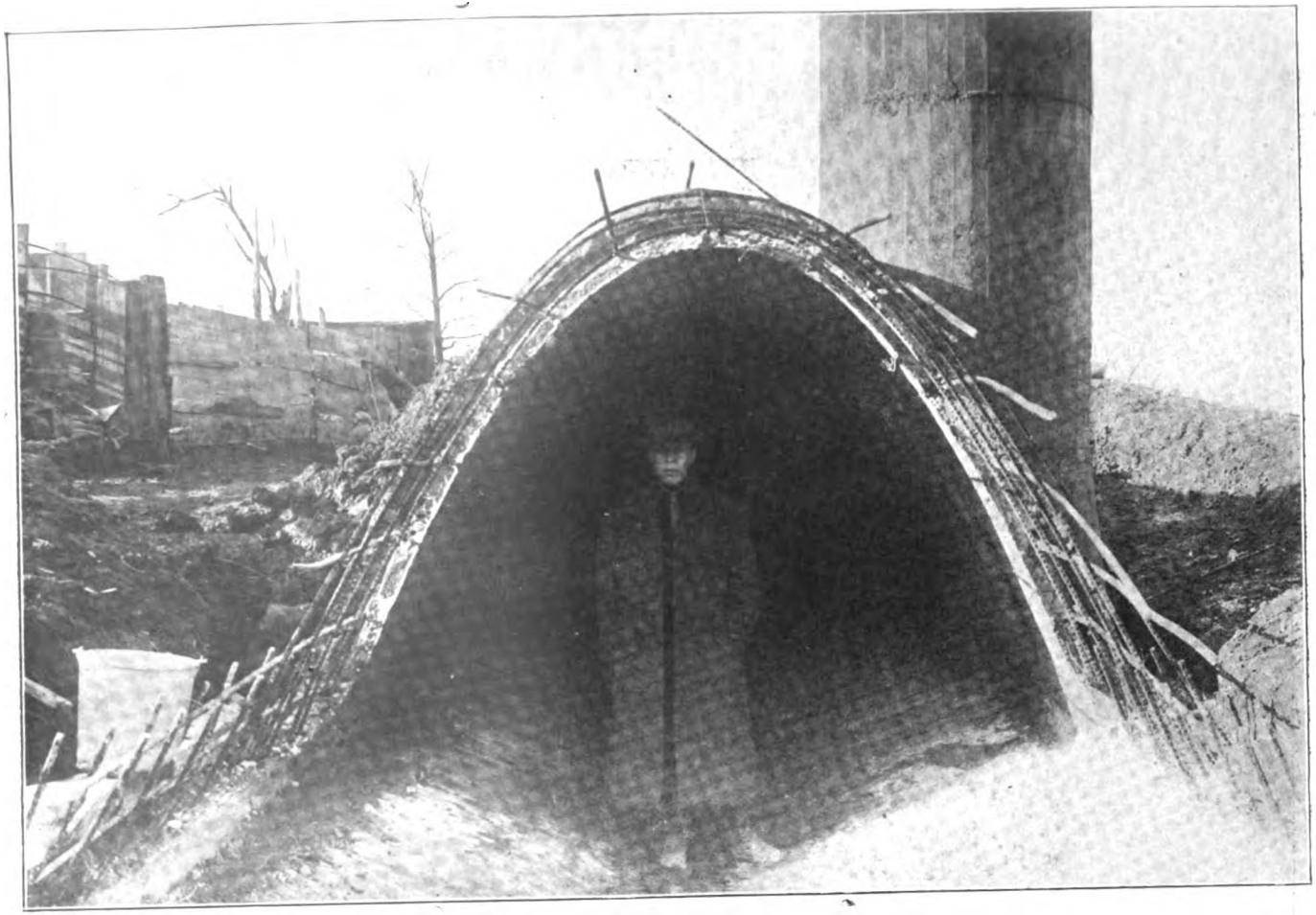
Fig. 46. Interior of "Dosing Chamber" of Septic Tank at Ames, Iowa, Showing "Alternating" Siphons.

and they work upon the organic matter in the sewage slowly trickling past them. In sand filters the bacteria are of the general class known as *aërobic* bacteria, or those which require oxygen to live. Hence the application of sewage must be *intermittent,* to allow each dose to

Fig. 47. Cross-Section of Intermittent Sand Filter.

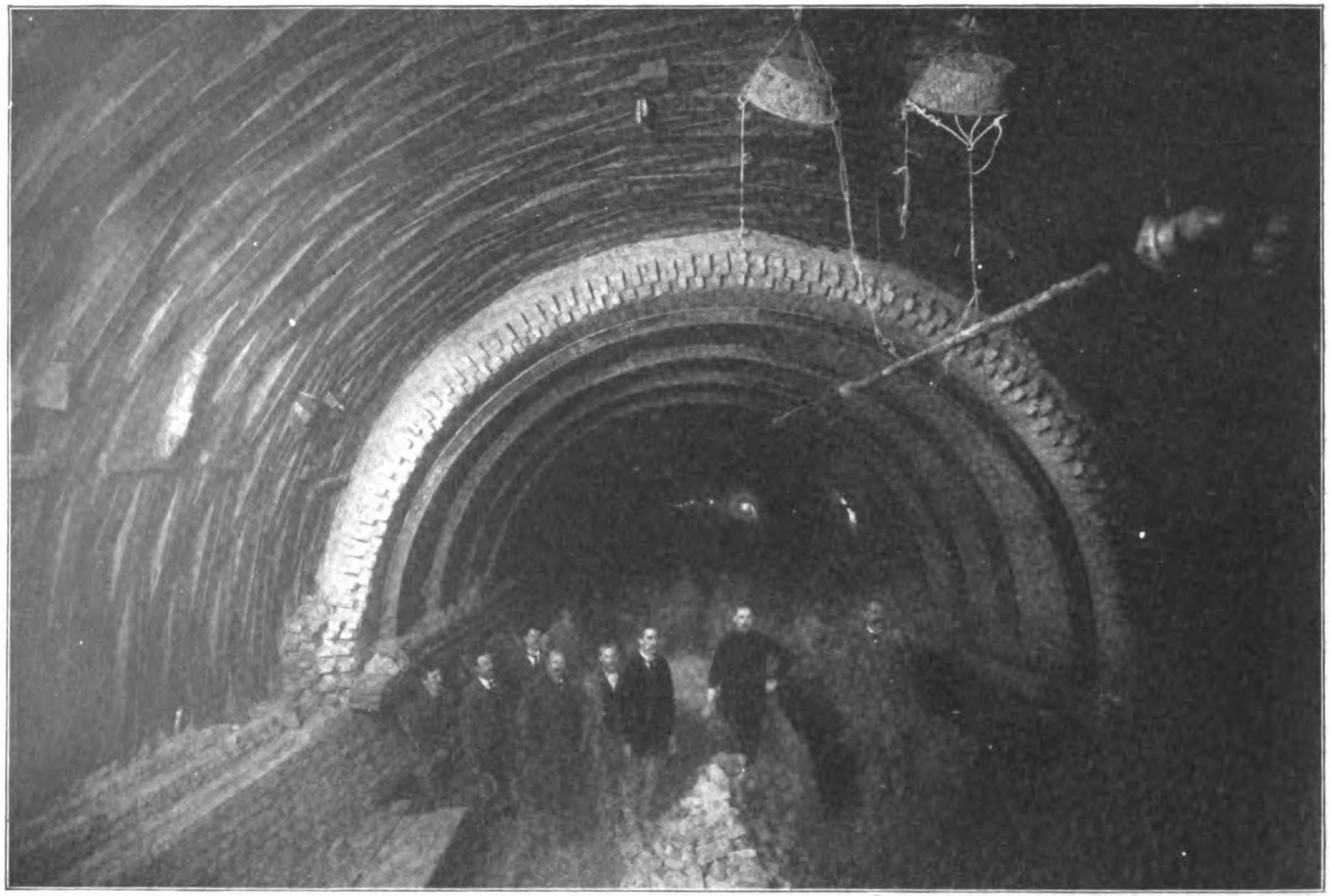
penetrate down into the sand out of sight, and draw air into the pores after it, before the next dose is applied.

Efficiency of Sand Filters. Sewage-disposal plants having sand filters should remove 85 to 98 per cent of the organic matter from the sewage, and 98 to 99.8 per cent of the bacteria.



CONSTRUCTION OF "HAPPY HOLLOW" SEWER, LOUISVILLE, KENTUCKY

View showing arch and invert, with longitudinal and transverse reinforcing bars; also, in right background, one of the concrete manholes, the top of which is at the new grade that will be formed by filling in after completion of the sewer.



LARGEST SEWER IN THE UNITED STATES

View of 39th Street Intercepting Sewer, Chicago, Ill., showing a portion of the wooden forms and brick lining. Length of sewer, 12,000 ft.; diameter, 24 ft. 10 in. external, and 20 ft. internal; bricks laid in "Utica" hydraulic cement, of which 60,000 barrels were used. This sewer is one of a system of similar sewers paralleling the shore of Lake Michigan, to prevent egress of sewage into the lake. Its level being 20 ft. below that of the lake, the sewage is pumped up to higher levels, and then flows westward by gravity into the new outlet afforded by the Drainage Canal.

Courtesy of Meacham & Wright, Chicago, Ill.

In Fig. 47 is given a cross-section of one of the intermittent sand filters shown in Fig. 43. Each of these filters is 200 feet long by 65 feet wide, by 2 feet 9 inches average depth. A large sewer-pipe from one of the alternating siphons passes down the center on top of each bed, with 4-inch openings each side every 10 feet for distributing the sewage evenly over the surface. The sand is 2 feet 6 inches deep, and is underlaid with a layer of graded pebbles 0 to 6 inches deep. Lines of 4-inch agricultural drain-tile 13 feet apart are provided to remove the filtered sewage.

In Fig. 48 is given a view of a similar sewage filter under construction. In this case considerable grading had to be done out into a lake to get room for the filters.

Fig. 49 is a view of a completed plant, consisting of a septic tank, with intermittent sand filters. The purified effluent from this plant is as clear and odorless as spring water.

123. Sprinkling Filters. These are made of coarse material, say $\frac{1}{8}$ inch to 1 inch in size. Sewage flowing upon such coarse material would pass through the large pores too quickly to receive much purification. Hence the sewage must be sprinkled upon the top surface in drops to insure its simply trickling over the surfaces of the pieces of filter material. There are many devices for distributing the sewage in this way, including, principally, traveling perforated arms, and spray nozzles. All the devices need constant, intelligent care to keep them in order.

The material of which sprinkling filters are made may be pebbles, crushed stone, crushed coke, or any hard, durable material, crushed to the proper size.

Sprinkling filters possess the great advantage over other types, of the very high rate of filtration possible, and the small filter area consequently required. Rates of 1,000,000 to 2,000,000 gallons per acre per day have been proposed. They are not so efficient, however, as sand filters.

Theory of Action of Sprinkling Filters. In the case of sprinkling filters, owing to the coarseness of the pieces of filtering material, and the fact that the sewage is applied in drops, and runs over the pieces of the filtering material in films, without filling the pores, sufficient air remains constantly in the pores of the filters to keep alive the aërobic bacteria of purification. Hence the application of the sewage

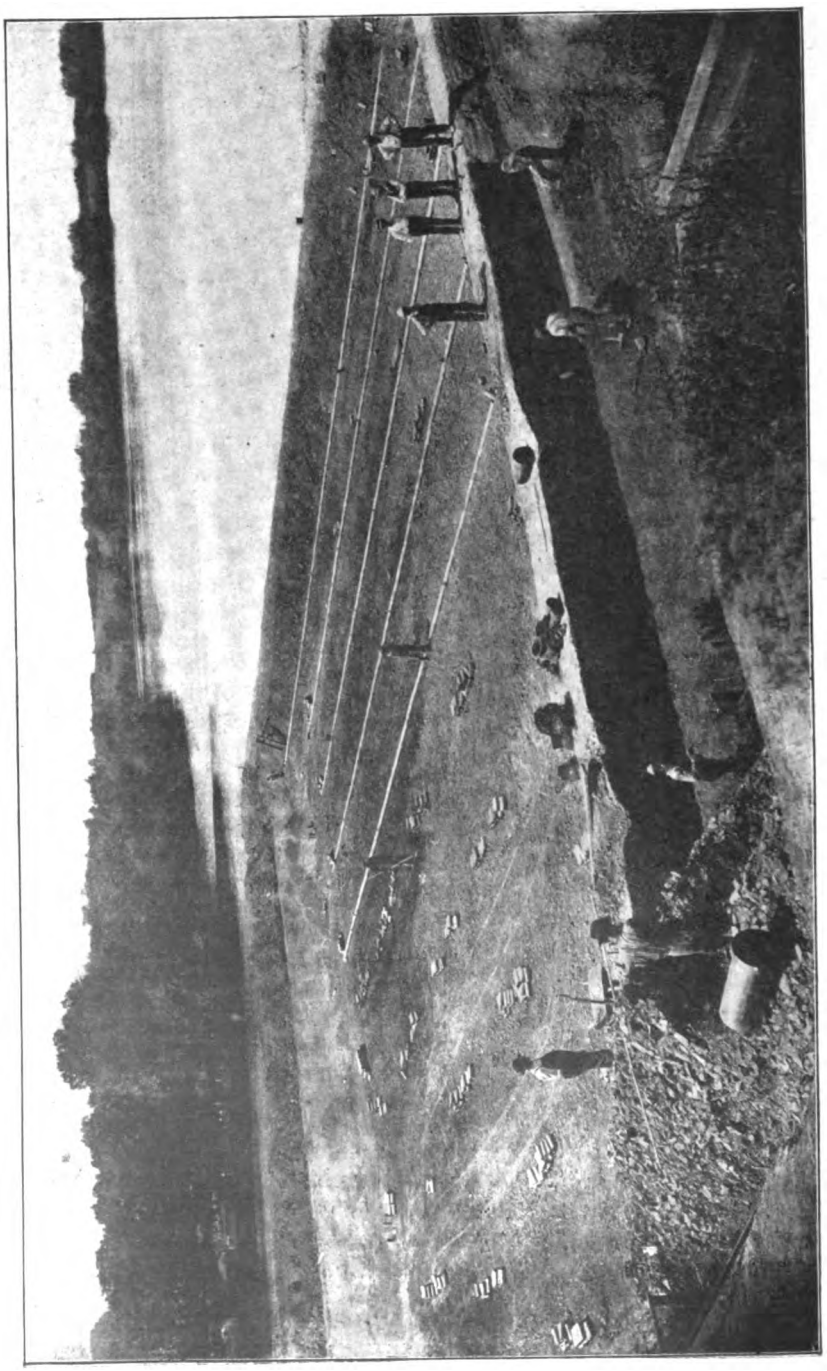


Fig. 48. "Intermittent" Sand Sewage Filters at Fairmont, Minn., under Construction.

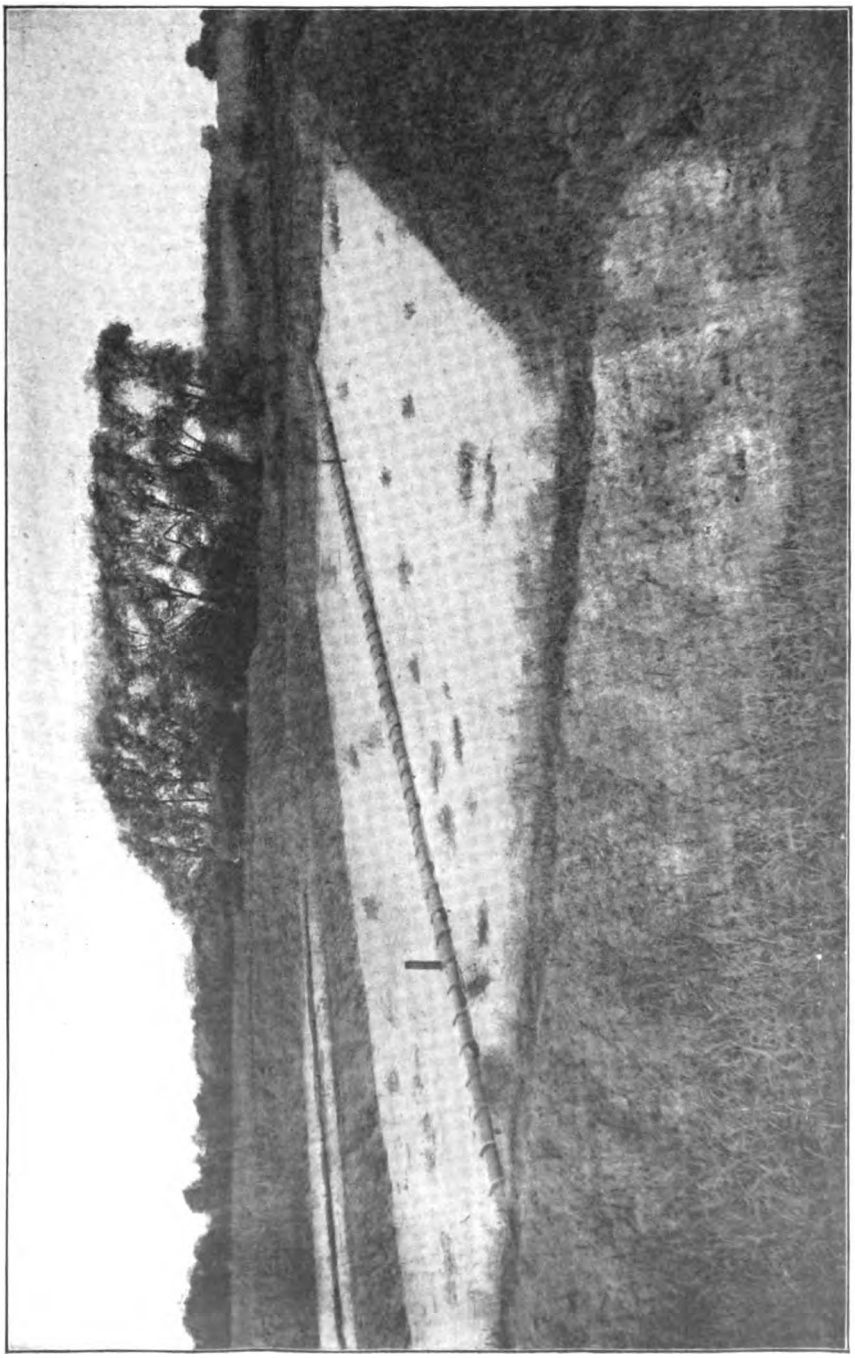


Fig. 49. View of Completed Sewage-Disposal Plant at Ames, Iowa, Consisting of a Septic Tank and Two "Intermittent" Sand Filters.

need not be intermittent as in the case of sand filters. However, the germs do not have time and opportunity to work so thoroughly upon the organic matter as in sand filters.

Efficiency of Sprinkling Filters. This is not nearly so high as for sand filters. Fine, black particles of partially purified organic matter often cloud the effluent to such an extent that settling tanks must be provided for clarification.

Sprinkling filters are suited best to large cities, and to cases where the highest efficiency of purification is not essential.

124. Maintenance of Sewage-Disposal Plants. Sewage-disposal plants, like other forms of apparatus, will not run themselves. For large cities, where men must be constantly employed to care for the

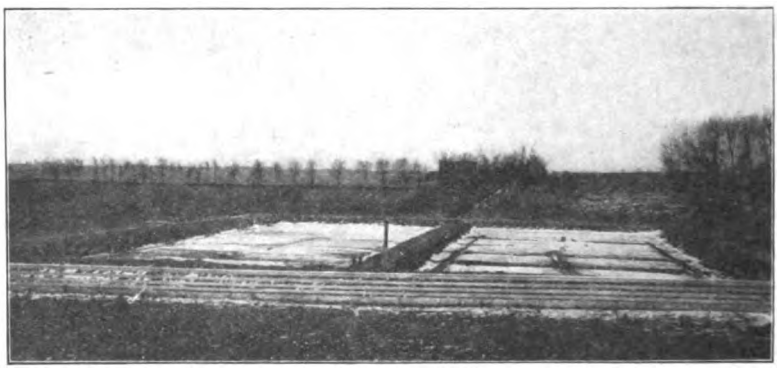


Fig. 50. Iowa State College (Ames, Iowa) Sewage Filters in Winter.

large plants, little trouble is experienced in securing proper care; but for small cities, sewage-disposal plants are often almost entirely neglected.

Every sewage-disposal plant should be visited at least once a day by an intelligent man, who should make sure at every visit that everything is operating properly, and who should remedy any trouble found.

Care of Tanks. Septic tanks require cleaning out about once a year. After the sludge is thoroughly dried, it should be hauled away and ploughed under for fertilizer. Besides this, the only care needed is to make sure that no passages are stopped up, that valves are arranged properly, and that siphons or other automatic apparatus work properly.

Care of Filters. Sand filters require to be raked or harrowed or dug or ploughed up, to loosen the surface, at intervals of a few days to two months, depending on the clarity of the sewage and on the rate of application of sewage. This is to keep the surface of the sand loose, so that the sewage can penetrate it. Otherwise the filter will become so water-tight that the sewage will continually flood it, which will drown the aërobic bacteria of purification.

At the approach of winter, the surfaces of sand filters should be ridged up with a plough, or by hand, into a succession of ridges and furrows. Ice, which forms only in very severe weather, will then be supported on the ridges, and will leave hollows underneath in the furrows for the next dose (see Fig. 50).

In case of sprinkling filters, the distributing devices require constant care, and the filter material may need occasional loosening up, or even washing or renewal. Sprinkling filters are not well adapted to very cold climates.

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